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SPECTROGRAPHIC OBSERVATIONS OF STANDARD VELOCITY STARS AT PULKOWA.

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THIS paper gives only the provisional results of the investigations of the velocities of the international fundamental stars. The new spectrograph of the Pulkowa Observatory was made by O. Töpfer, of Potsdam, according to his model III, and may be regarded as a duplicate of the Potsdam spectrograph III A. It has a collimator of 550 mm focal length, three simple flint prisms, and two cameras, designated as A and B, of respectively 610 and 415 mm focal length. The prisms are set at minimum deviation for $H\gamma$. The whole spectrograph is provided with Hartmann's automatic heating device.

The spectrum of iron has been for the most part used for comparison. Until October 9, 1902, a Ruhmkorff coil with four Leyden jars gave the spark spectrum. Since that date I have employed an arc lamp of 100 volts and 2–4 amperes. A ground-glass disk is placed between the arc and the slit when the comparison spectrum is being taken.

The uniformity of intensity of the beam of light emerging from the collimator lens was tested by introducing a photo-

graphic plate. It turns out that the lens is uniformly illuminated for the artificial source, but this is not the case for the stars (*a Lyrae* and *a Aurigae*). For western hour angles the upper half of the lens is more strongly illuminated, for eastern hour angles the lower. When the correcting lens was removed, there appeared to be a diametral zone, parallel to the slit, having but faint illumination. In this, perhaps, lies the reason why on our spectrograms the stellar lines always appear to be inclined with respect to the comparison lines, if the star's image has been rigorously kept at the same point on the slit. I will here pass over the other investigations of the spectrograph which I have made according to Hartmann's methods.

I must admit that I am not satisfied with any of our spectrograms, since, in spite of all my efforts, the lines never seem sharp enough. I cannot now decide whether the cause lies in the thirty-inch objective, which gives much diffuse light, or in the prisms.

Stars fainter than the third magnitude, situated near the equator, can be observed at Pulkowa only with difficulty, for the two reasons: (1) the strong absorption of the ultra-violet rays, and (2) the increase in size of the star's disk with decreasing altitude. The necessary exposure time is thus greatly increased for such stars, which explains why I have been unable to observe *γ Piscium*. I would remark in general that for fundamental velocity determinations only such stars should be selected as do not require too protracted an exposure.

The number of my observations is greater than according to the program, for the reason that the spectrograph was received only shortly before the work began, and the changes made during the investigation of the spectrograph rendered a repetition of the observations desirable. The weather hindered my securing the plates on the dates of the program.

The measurements were made with the old Töpfer microscope. The screw was investigated three times, each revolution being separately measured. I employed a magnifying power of one thousand in these investigations. The small corrections were applied to the readings for the settings on the stellar lines. The

pitch of the screw is ¼ mm. In measuring the stellar spectra, I have usually employed a magnifying power of 20. The stellar spectrograms taken with camera A are measurable for an extent of 29 mm; with camera B, 25 mm. Each plate was twice measured, with the violet respectively toward the left and toward the right, and the mean was taken from the two measures. At the conclusion of a set of measures I convinced myself that the position of the plate had remained unchanged during the operation.

In the reductions I followed for the most part Hartmann's methods.[1] The constants of the formula I computed for the cameras for a temperature of 0° C. For this the measures of the iron comparison lines on each stellar plate were used after they have been reduced to 0° C. by a curve. The normal readings thus obtained for the iron comparison lines gave the reference points for each plate. I formed the differences, Normal—Plate, smoothed them out, and employed the adjusted differences for reducing the stellar lines to the normal scale. The wave-lengths could then be computed from the formula, and after comparison with Rowland's wave-lengths the displacement and finally the velocity in the line of sight were obtained. The reductions to the Sun were made with Schlesinger's tables, and are designated by V_a. V_d is the correction for the diurnal motion, and C that for the curvature of the lines computed for the mean wave-length. The corrections are as follows for the two cameras, for a mean wave-length of 432 $\mu\mu$, for three arguments:

Camera B		Camera A	
Argument	C	Argument	C
0.57 rev.	—0.28 km	0.78 rev.	—0.07 km
0.89	—0.55	1.00	—0.14
1.92	—2.21	3.00	—0.41

In the selection of the wave-lengths from Rowland's table a certain arbitrary element has appeared, which may change the

[1] *A. N.*, 155, 81–118, 1901.

velocities obtained by 2km. As illustrations of this I give below the velocities of β *Geminorum*, α *Boötis*, and γ *Cephei*.

The dispersion and scale for the two cameras are as follows:

Camera A			Camera B	
λ 4207	47″ per t.-m.	7.2 t.-m. per mm	λ 4205	10.5 t.-m. per mm
4297	41	8.4	4325	12.9
4427	33	10.2	4525	17.1

The normal readings for the settings on the iron lines follow, with the formulæ derived from them:

NORMAL READINGS FOR THE IRON LINES.

(In Revolutions for 0°C.)

Camera A		Camera B	
λ	n	λ	n
4191.611	5.245	4202.195	8.359
99.256	9.560	36.112	20.875
4204.119	12.280	50.945	26.127
10.521	15.814	60.640	29.489
19.523	20.727	71.934	33.336
22.387	22.277	82.565	36.892
33.771	28.354	94.290	40.747
36.118	29.587	99.410	42.405
38.980	31.100	4308.080	45.184
82.567	53.139	15.262	47.462
94.290	58.808	25.940	50.799
4308.081	65.338	37.216	54.260
15.255	68.693	52.908	58.986
37.219	78.709	76.108	65.763
52.910	85.665	83.720	67.935
76.104	95.653	4404.929	73.869
83.724	98.868	15.301	76.709
4404.929	107.615	27.490	79.988
15.301	111.796	47.912	85.359
27.490	116.634	59.301	88.291
		76.185	92.556
		4528.798	105.245

FORMULÆ.

Camera A.

$$\lambda = 3276.923 + \left(\frac{[4.1143394]}{871.363 - n}\right)^{\frac{1}{0.6}}$$

$$\epsilon = \pm\sqrt{\frac{\Sigma(\epsilon)^2}{m-1}} = \pm 0.0061 \text{ t.-m.}$$

Camera B.

$$\lambda = 3355.245 + \left(\frac{[3.7727324]}{652.237 - n}\right)^{\frac{1}{0.6}}$$

$$\epsilon = \sqrt{\frac{\Sigma(\epsilon)^2}{m-1}} = \pm 0.0059 \text{ t.-m.}$$

(Numbers in brackets [ ] are logarithms.)

RADIAL VELOCITY FOR A DISPLACEMENT OF 1 MICROMETER DIVISION.

Camera A		Camera B	
λ	Velocity	λ	Velocity
4190	1.26 km	4200	1.87 km
4250	1.37	4250	2.02
4300	1.47	4300	2.16
4350	1.57	4350	2.37
4400	1.67	4400	2.46
4430	1.71	4450	2.60
		4500	2.74
		4550	2.90

All computations were made in duplicate.

To convince myself of the power of the new spectrograph, I have a few times photographed, on the same plate, the spectrum of the east and west limbs of the Sun at extremities of the equator. The spectrum of the center of the disk could also be taken, by a special attachment, on the same plate. The solar rotation can be determined from such plates. Lantern slide plates of Thomas were used. I obtained the following results from two plates taken on June 13, 1902:

Line	First Plate		Second Plate	
	Relative Displacement	Velocity of Solar Equator	Relative Displacement	Velocity of Solar Equator
	p		p	
λ 4233.8	2.7	1.80 km	2.9	1.87 km
27.6	3.0	1.98	3.0	1.92
22.4	3.0	1.97	2.5	1.57
15.7	2.8	1.81	2.9	1.82
10.5	3.5	2.28	3.0	1.87
04.1	2.4	1.53	3.7	2.30
02.2	3.9	2.48	2.3	1.40
4199.2	3.3	2.09	2.6	1.58
95.6	3.9	2.46	3.2	1.91
91.6	2.7	1.69	3.0	1.88
87.2	2.4	1.49	3.0	1.87
85.1	2.9	1.80	3.4	2.11
81.9	1.9	1.17	3.5	2.16
77.8	2.0	1.23	2.4	1.47
75.0	3.7	2.25	3.2	1.95
71.1	2.8	1.70	2.5	1.52
67.4	3.6	2.18	3.5	2.11
58.9	2.6	1.56	2.8	1.67
57.0	2.5	1.48	3.2	1.90
55.0	3.3	1.92	3.9	2.31
4144.0	3.2	1.85	2.7	1.57
	Mean	1.84 ± 0.09 km		1.84 ± 0.063 km

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Object	Camera	Date— Gr. M. T.	Duration	Hour Angle	Slit-Width	Comparison Spectrum	Temperature Beginning	Temperature End	Remarks
		1902	m	h m		s			
α Persei ...	B	Oct. 25.409	51	E 1 15	17	*Fe* 6 Mid.	+ 2.2 °C	+ 2.2 °C	
	B	26.373	30	E 2 5	18	" 10	− 1.5	− 1.5	
	B	31.417	32	E 0 40	18	" 9	+ 4.0	+ 4.0	
	B	Nov. 6.371	30	E 0 23	18	" 10	− 2.0	− 2.0	Diffuse
	B	8.379	31	E 1 2	18	" 10	− 1.4	− 1.4	
	B	15.413	30	W 0 13	18	" 12	− 3.7	− 3.7	
	A	26.314	57	E 1 27	18	" 20	− 9.6	− 9.6	
	A	Dec. 19.363	35	W 1 15	18	" 25	− 9.8	− 9.8	
		1903							
β Gemino-	A	Jan. 31.448	38	W 1 46	19	*Fe* 30	− 3.5	− 3.5	
rum	A	Feb. 13.364	42	W 0 35	18	" 30	− 7.7	− 7.7	
	A	22.248	43	W 0 41	18	" 20	+ 0.4	+ 0.5	
	A	24.233	48	E 1 52	18	" 30	− 0.7	......	
	A	Mar. 2.424	49	W 3 9	19	" 30	+ 1.1	+ 1.1	
	A	3.383	28	W 2 14	19	" 3	+ 0.5	+ 0.5	No gr. gl.; w'k
	A	13.380	40	W 1 49	19	" 30	+ 1.0	+ 1.0	Wedge toward violet
	A	14.331	42	W 1 40	18	" 30	− 2.7	......	
	A	21.377	41	W 3 17	18	" 2	− 1.8	− 1.75	No ground gl.
		1903							
α Boötis	A	Apr. 15.393	22	E 1 14	15	*Fe* 30	+ 3.3	......	Camera below
	A	17.420	44	E 0 28	12	" 35	+ 2.3	+ 2.3	"
	A	21.397	40	E 0 45	16	" 35	+ 4.0	+ 4.0	"
	A	May 8.366	58	E 0 28	16	" 30	+ 5.5	+ 5.5	"
	A	9.369	50	E 0 15	16	" 30	+ 2.8	+ 2.8	Camera above
	A	16.340	48	E 0 29	17	" 25	+ 8.1	+ 8.1	"
	A	17.352	55	E 0 7	16	" ?	+ 7.7	+ 7.7	
	B	27.352	43	W 0 31	14	" 10	+11.6	+11.6	Camera below
	B	July 21 334	28	W 3 52	15	" 9	+11.0	+11.0	"
		1902							
γ Aquilae ..	B	Aug. 5.368	66	E 0 5	15	*Fe* and *H* 60	+14.4	+14.0	
	B	7.327	62	E 0 53	17	" 60	+14.3	+14.6	Poor
	B	13.359	97	W 0 19	16	" 60	+12.6	+12.6	
	B	15.325	70	E 0 21	16	" 60	+10.6	+10.6	
	B	18.361	66	W 0 42	16	" 60	+12.5	+12.4	
	B	19.359	60	E 0 38	15	" 60	+13.5	+13.3	Image good
	B	26.327	30	W 0 18	16	" 60	+11.0	+11.0	Faint
		1903							
	B	July 21.382	61	E 0 39	15	*Fe* 9	+11.0	+11.0	Faint
	B	28.423	66	W 0 45	15	" 9	+15.8	+15.8	
	B	Aug. 7.383	60	W 0 29	20	" 9	+13.2	+13.3	
		1902							
ε Pegasi	B	Aug. 19.408	65	E 0 2	15	*Fe* and *H* 60	+13.3	+13.3	Poor
	B	Sept. 10.326	60	E 0 34	18	" 60	+ 9.3	+ 9.5	
	B	11.316	60	E 0 49	18	" 60	+ 8.5	+ 8.5	
		1903							
	B	Aug. 7.430	67	E 0 13	20	*Fe* 9	+13.3	+13.3	
	B	10.397	73	E 0 54	20	" 10	+10.0	+10.0	
	B	19.417	62	W 0 10	20	" 10	+11.5	+11.5	
	B	27.438	60	W 0 11	20	" 15	+ 9.4	+ 9.4	Objective half-covered
		1903							
γ Cephei ...	B	Sept. 3.426	72	E 0 35	20	*Fe* 10	+11.2	+11.2	
	B	7.393	71	E 1 7	20	" 12	+14.3	+14.3	
	B	8.375	81	E 1 30	20	" 10	+12.4	......	
	B	13.383	75	E 0 57	20	" 12	+ 9.3	9.3	Cloudy; weak
		1903							
Jupiter	B	Sept. 15.404	50	E 0 2	16	*Fe* 6	+ 9.5	+ 9.5	Camera above
	B	17.397	48	E 0 3	17	" 5	+11.1	+11.1	"
	B	18.396	41	0 0	17	" 5	+11.5	+11.5	"
	B	19.393	48	W 0 1	17	" 5	+10.5	+10.7	"
	B	21.413	47	W 0 38	17	" 5	+11.0	+11.0	Camera below
	B	22.395	49	W 0 18	17	" 5	+10.3	+10.3	"
	B	23.384	42	W 0 6	17	" 5	+ 9.9	+ 9.9	"
	B	23.422	60	W 0 58	17	" 5	+ 9.9	+ 9.8	"
		1903							
Mars	A	Mar. 29.389	36	E 0 47	14	*Fe* 30	+ 4.7	+ 4.7	Camera below
	A	29.420	40	E 0 3	14	" 35	+ 4.7	+ 4.7	"
	A	30.389	34	E 0 42	14	" 30	+ 3.2	+ 3.2	"
	A	Apr. 13.352	34	E 0 21	13	" 30	+ 9.5	+ 9.5	"
	A	14.360	41	E 0 5	12.5	" 35	+ 5.0	+ 5.0	"
	A	15.357	60	E 0 5	12.5	" 35	+ 3.4	+ 3.2	"
	A	17.377	59	W 0 36	12	" 35	+ 2.3	+ 2.3	"

The planets *Mars*, *Venus*, and *Jupiter* were also observed and the results compared with the radial velocities deduced from the data in the Nautical Almanac. I give here the determinations for *Mars* and *Jupiter* only, as the plates of *Venus* constitute a large mass of material and will be specially discussed. I must state that in case of the planets my settings were made on the two edges of the spectra, and then the means were taken. It was very important in the case of *Jupiter* to hold the slit at the same point, as the rapid rotation may otherwise affect the results.

On combining the results given below the radial velocities show a worse agreement than would have been expected *a priori* with such an instrument. It may be that the method of reduction is not sufficiently rigorous, particularly in case of *a Boötis*, the spectrograms of which were taken with the wedge *under* the plate-holder, in a different position from that for the other stars. I am convinced that the second series of observations of the standard velocity stars will give better accordance than the present series.

Greenwich Mean Time is used throughout in this article.

MARS.

1903, March 29.389 G. M. T.

Solar Wave-Length	Velocity
4274.958	−1.96 km
4307.017	3.00
15.209	0.84
52.030	2.75
59.784	2.75
4408.622	1.02
No. of comp. lines	7
V_d	+0.04
Mean	−2.06
Computed vel.	−1.81

MARS.

1903, March 29.420.

Solar Wave Length	Velocity
4292.290	−2.03 km
94.273	1.96
4307.017	4.32
15.209	3.89
20.207	1.80
52.083	0.28
52.908	0.14
59.784	1.79
4408.622	2.38
15.293	4.82
16.074	1.83
27.482	3.72
No. of comp. lines	9
V_d	0.00
Mean	−2.41
Computed vel.	−1.84

MARS.

1903, March 30.389.

Solar Wave-Length	Velocity
4294.273	−1.75
4315.262	1.95
40.634	0.41
52.007	0.62
4408.582	1.70
15.293	0.75
27.420	1.42
No. of comp. lines	7
V_d	+0.04
Mean	−1.23
Computed vel.	−1.44

MARS.

1203, April 13.352.

4352.007	+2.07
71.368	3.64
4404.927	5.41
08.582	3.06
15.293	4.68
27.420	3.86

No. of comp. lines 7
V_d +0.02
Mean +3.74
Computed vel. +3.73

1903, April 14.360.

4294.301	+3.63
4306.937	2.44
15.138	4.51
52.007	3.44
83.720	4.72
95.286	3.62
4408.622	2.38
27.482	2.30

No. of comp. lines 6
V_d 0.00
Mean +3.38
Computed vel. +4.05

1903, April 15.357.

4294.273	+4.89
4306.858	5.85
15.138	5.00
25.939	4.30
40.634	5.11
51.930	7.57
59.784	−0.08
4408.582	+3.53
27.420	3.46

No. of comp. lines 7
V_d 0.00
Mean +4.33
Computed vel. +4.36

MARS.

1903, April 17.377.

4294.273	+4.26
4306.858	9.04
15.138	7.71
52.007	5.30
52.908	6.75
59.784	1.99
4404.927	3.88
08.622	5.37
27.482	4.00

No. of comp. lines 6
V_d +0.03
Mean +5.37
Computed vel. +4.97

JUPITER.

1903, Sept. 15.404.

Solar Wave-Length	Velocity
4237.240	+3.82
45.455	2.05
54.505	6.97
67.985	4.50
74.958	3.93
88.230	2.24
95.289	0.21
4352.083	0.96
59.784	4.13
71.442	2.06
95.286	4.98

No. of comp. lines 11
V_d 0.00
Mean +3.26
Computed vel. +2.09

JUPITER.

1903, Sept. 17.397.

Solar Wave-Length	Velocity
4229.868	+4.26
37.334	0.56
43.608	2.54
45.520	2.12
46.996	5.72
54.505	7.96
74.958	3.79
91.545	1.82
4320.992	2.92
52.083	6.27
71.442	5.15
95.286	2.91

No. of comp. lines 13
V_d 0.00
Mean +3.84
Computed vel. +3.11

1903, Sept. 18.396.

Solar Wave-Length	Velocity
4254.505	+2.89
74.958	1.68
92.320	1.96
4340.634	5.74
52.083	5.37
69.941	6.45
71.442	4.66
4401.613	3.00
27.482	1.15

No. of comp. lines 12
V_d 0.00
Mean +3.65
Computed vel. +3.63

JUPITER.

1903, Sept. 19.393.

4210.491	+3.63
19.484	1.56
49.952	3.47
45.422	6.78
60.581	4.44
74.911	3.93
91.276	1.61
4315.209	1.17
71.368	5.28
4402.575	4.70

No. of comp. lines 11
V_d 0.00
Mean +3.66
Computed vel. +4.15

1903, Sept. 21.413.

4222.382	+7.52
37.240	5.03
45.422	8.19
54.505	7.33
74.958	7.93
91.276	5.03
4315.262	5.01
52.083	3.93
59.784	5.64
67.955	4.48
79.941	5.01
95.285	3.82

No. of comp. lines 10
V_d −0.03
Mean +5.74
Computed vel. +5.19

JUPITER.

1903, Sept. 22.395.

4210.561	+2.49
15.703	5.90
22.382	5.60
37.314	2.76
40.014	4.46
43.608	3.39
54.505	7.75
74.958	5.82
92.290	5.73
4303.669	5.85
15.209	5.42
52.083	3.93
59.809	8.06
71.442	6.11
4427.482	6.10

No. of comp. lines 14
V_d 0.00
Mean +5.29
Computed vel. +5.69

1903, Sept. 23.384.

4243.442	+5.30
54.505	2.89
74.911	2.88
88.149	6.84
92.290	4.05
4318.817	3.82
40.634	3.73
52.007	6.06
59.784	7.42
71.368	5.76
94.943	4.97

No. of comp. lines 10
V_d 0.00
Mean +4.88
Computed vel. +6.20

JUPITER.

1903, Sept. 23.422.

4247.591	+7.91
54.505	4.84
74.958	5.19
91.276	4.38
4315.209	5.42
18.817	7.56
40.634	7.73
52.007	5.03
59.784	9.15
71.368	6.48
95.285	5.53
4408.622	6.66
27.420	8.66

No. of comp. lines 12
V_d −0.06
Mean +6.50
Computed vel. +6.23

SUMMARY.

MARS		*JUPITER*	
Date	Comp.−Obs.	Date	Comp.−Obs.
March 29.....	+0.21	Sept. 15....	−1.17
29.....	+0.57	17....	−0.73
30.....	−0.25	18....	−0.02
April 13.....	+0.01	19....	+0.49
14.....	+0.67	21....	−0.52
15.....	+0.03	22....	+0.40
17.....	−0.43	23....	+1.32
		23....	−0.21
Mean......	+0.12 km	Mean.....	−0.06 km

α PERSEI.

1902, Oct. 25.409. Hour angle E $1^h\ 15^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4202.198	− 8.84	4320.992	−15.82
36.112	17.91	52.007	19.70
50.945	15.38	74.775	10.90
54.505	13.53	76.107	12.61
60.551	17.17	83.720	17.44
94.273	17.73	4404.927	17.02
4308.081	16.51	50.654	15.50
14.381	18.21	64.731	15.50

No. of comp. lines 14; ϵ ±2.8; ϵ_0 ±0.7

Mean −15.61; V_a +12.27; V_d + 0.06; C − 0.30; Rad. vel. − 3.58

1902, Oct. 26.313. Hour angle E $2^h\ 5^m$.

4202.198	− 8.49	4314.381	−16.61
15.703	14.59	20.992	12.00
26.904	17.10	52.007	12.55
36.112	18.90	76.107	9.51
50.945	17.00	83.720	12.11
54.505	14.18	95.201	12.35
58.389	15.30	4404.927	12.87
94.301	12.57	64.731	14.44
99.296	12.88	81.438	14.59
4308.081	13.02	4522.974	16.84

No. of comp. lines 14; ϵ ±2.6; ϵ_0 ±0.6

Mean −13.90; V_a +11.89; V_d + 0.10; C − 0.30; Rad. vel. − 2.21

1902, Oct. 31.417.

4215.703	−14.80	4320.992	−13.11
36.112	12.18	25.939	14.21
50.945	13.76	51.930	13.23
54.505	13.53	74.775	12.58
71.934	12.43	76.107	9.51
88.075	10.35	83.720	15.26
94.273	14.73	4404.927	13.82
4308.081	14.48	64.617	10.61
14.281	10.50	76.185	11.48
15.209	14.55	4508.027	13.63

No. of comp. lines 13; ϵ ±1.7; ϵ_0 ±0.4

Mean −12.98; V_a + 9.75; V_d + 0.05; C − 0.30; Rad. vel. − 3.48

α PERSEI.

1902, Nov. 6.371. Hour angle E $0^h\ 23^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4250.945	− 9.74	4320.992	− 7.77
54.505	12.75	40.634	7.05
58.389	12.40	52.007	10.20
71.945	8.63	67.955	11.32
74.958	8.98	83.720	10.94
94.273	11.52	4404.927	13.07
4308.081	11.48	62.897	10.08
13.034	10.85	4501.448	9.46
14.381	11.53		

No. of comp. lines 13; ϵ ±1.7; ϵ_0 ±0.4

Mean −10.46; V_a + 7.33; V_d + 0.01; C − 0.30; Rad. vel. − 3.42

1902, Nov. 8.379. Hour angle E $1^h\ 9^m$.

4215.703	− 8.46	4308.081	−10.37
26.704	11.28	14.381	11.33
27.606	14.12	44.597	9.80
36.112	14.58	52.007	9.03
50.945	8.75	83.720	9.04
58.389	12.26	4404.927	6.94
99.296	8.78	81.438	8.36

No. of comp. lines 13; ϵ ±2.2; ϵ_0 ±0.6

Mean −10.22; V_a + 6.46; V_d + 0.03; C − 0.30; Rad. vel. − 4.03

1902, Nov. 15.413. Hour angle W $0^h\ 13^m$.

4215.703	− 7.92	4308.081	−8.00
22.875	10.15	14.381	8.69
50.945	7.33	20.992	2.92
54.505	6.27	52.083	8.54
88.075	7.55	4404.927	3.47
4300.211	7.11	81.464	5.49

No. of comp. lines 14; ϵ ±2.2; ϵ_0 ±0.6

Mean −6.95; V_a +3.35; V_d 0.00; C −0.30; Rad. vel. −3.90

α PERSEI.

1902, Nov. 26.314. Hour angle E $1^h\ 27^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4226.904	+0.21	4288.075	−1.89
46.996	0.35	4315.209	0.14
50.945	0.49	25.939	+1.39
54.505	2.33	52.007	−0.21
58.345	−1.34	95.201	+3.75
71.934	2.11	4404.927	3.74
No. of comp. lines	13	Mean	+1.21
ϵ	±1.6	V_a	−1.58
ϵ_0	±0.5	V_d	+0.06
		C	−0.07
		Rad. vel.	−0.38

1902, Dec. 19.363. Hour angle W $1^h\ 15^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4226.904	+ 8.44	4308.081	+8.13
36.112	7.64	14.381	9.52
58.389	8.38	15.209	8.40
71.945	13.90	25.921	8.73
88.075	10.76	52.007	9.99
94.273	10.40	83.720	9.85
4300.211	13.04	4404.927	9.39
No. of comp. lines	13	Mean	+ 9.68
ϵ	±1.7	V_a	−11.68
ϵ_0	±0.5	V_d	− 0.04
		C	− 0.07
		Rad. vel.	− 2.11

β GEMINORUM.

1903, Jan. 31.448. Hour angle W $1^h\ 46^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4185.058	+15.83	4246.251	+11.93
92.782	9.36	47.591	16.94
4210.523	9.33	50.959	17.07
19.580	12.43	54.505	17.27
22.382	14.78	4315.209	10.70
38.919	14.77	53.467	11.71
40.039	12.66	4404.927	14.46
45.520	11.94		
No. of comp. lines	19	Mean	+13.41
ϵ	±2.7	V_a	− 9.54
ϵ_0	±0.7	V_d	− 0.09
		C	− 0.07
		Rad. vel.	+ 3.71

β GEMINORUM.

1903, Feb. 13.364. Hour angle W $0^h\ 35^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4185.058	+22.07	4236.168	+22.38
4200.148	15.43	92.263	19.00
19.580	14.71	4314.381	18.84
22.382	20.81	15.209	15.63
36.160	15.92	40.634	21.55
40.014	20.57	52.083	17.16
45.520	15.82	52.931	20.74
46.996	20.40	58.879	19.19
47.591	20.53	69.784	20.83
50.959	18.76	4404.927	15.25
54.505	23.62	15.293	21.06
55.002	20.17	27.482	14.50
68.138	17.92		
No. of comp. lines	19	Mean	+18.91
ϵ	±2.7	V_a	−15.62
ϵ_0	±0.6	V_d	− 0.03
		C	− 0.14
		Rad. vel.	+ 3.12

1903, Feb. 22.343. Hour angle W $0^h\ 41^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4187.971	+20.05	4294.301	+25.76
4200.148	24.84	4308.081	23.58
19.580	23.16	14.381	23.69
22.382	25.32	15.262	20.50
33.772	25.20	19.030	17.07
36.160	25.62	37.414	16.42
39.107	19.80	40.634	24.40
40.014	25.10	52.718	18.46
45.520	23.01	53.044	20.46
46.996	26.12	58.879	25.18
47.591	26.20	59.784	22.21
50.287	26.53	69.941	21.47
50.959	26.53	71.442	19.62
54.505	27.49	76.107	22.47
68.138	19.67	83.720	26.13
74.958	27.36	4404.927	18.52
92.290	24.58	15.293	23.97
No. of comp. lines	20	Mean	+23.12
ϵ	±3.0	V_a	−19.38
ϵ_0	±0.5	V_d	− 0.04
		C	− 0.14
		Rad. vel.	+ 3.55

β GEMINORUM.

1903, Feb. 24.233. Hour angle E $1^h\ 52^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4185.058	+26.72	4292.450	+19.56
99.267	24.85	94.301	25.90
4200.148	21.42	4314.430	25.51
19.580	23.31	15.262	20.78
22.382	23.19	40.634	24.80
36.160	23.79	52.083	23.50
40.014	25.89	59.784	24.48
45.520	21.83	69.941	26.49
46.996	24.64	76.107	24.74
50.287	24.62	83.720	26.13
54.505	27.89	4404.927	21.45
55.134	19.59	15.293	24.25
86.168	22.80	27.482	17.81

No. of comp. lines	18	Mean	+23.69
ϵ	±2.5	V_a	−20.10
ϵ_0	±0.5	V_d	+ 0.10
		C	− 0.14
		Rad. vel.	+ 3.55

1903, March 2.424. Hour angle W $3^h\ 9^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4188.019	+25.85	4294.301	+28.63
4200.148	28.35	4314.381	27.45
19.580	25.44	15.262	20.01
36.279	21.66	55.599	25.01
39.107	24.61	53.044	23.69
40.039	28.07	59.784	28.27
47.634	27.07	71.368	24.07
74.958	29.25	4404.927	22.20
88.230	27.76	15.293	26.34

No. of comp. lines	20	Mean	+25.76
ϵ	±2.6	V_a	−22.32
ϵ_0	±0.6	V_d	− 0.15
		C	− 0.14
		Rad. vel.	+ 3.15

1903, March 3.383. Hour angle W $2^h\ 14^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4185.058	+27.86	4294.301	+28.14
4219.580	25.11	4314.381	28.70
39.107	22.13	15.138	29.53
40.014	25.53	40.634	25.23
45.520	26.27	52.007	25.78
46.996	27.32	52.931	27.35
50.959	27.23	4404.927	20.49
74.958	28.62	15.293	31.38

No. of comp. lines	18	Mean	+26.67
ϵ	±2.0	V_a	−22.64
ϵ_0	±0.5	V_d	− 0.10
		C	− 0.14
		Rad. vel.	+ 3.79

β GEMINORUM.

1903, March 13.380. Hour angle W $1^h\ 49^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4236.112	+28.25	4371.368	+29.48
37.339	25.48	4408.582	28.96
40.014	28.00	27.482	28.03
45.455	26.26	35.321	26.98
46.996	30.78	42.510	34.48
74.958	31.15	59.301	32.33
87.117	28.46	79.576	32.46
4315.138	29.12	73.031	29.43
37.216	30.97	76.214	31.33
52.007	29.41	82.438	28.96
52.931	33.12	4522.802	28.84
58.879	29.50	28.798	24.96
59.784	31.91	35.741	32.25

No. of comp. lines	12	Mean	+29.34
ϵ	±2.3	V_a	−25.57
ϵ_0	±0.5	V_d	− 0.09
		C	− 0.14
		Rad. vel.	+ 3.54

1903, March 14.331. Hour angle W $1^h\ 40^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4250.945	+26.45	4359.784	+27.09
74.911	29.33	83.720	28.38
88.134	28.73	4404.927	26.56
94.204	30.73	15.293	31.78
4313.034	25.24	27.482	27.68
52.007	28.03	59.301	29.98
52.908	29.35		

No. of comp. lines	14	Mean	+28.41
ϵ	±1.8	V_a	−25.81
ϵ_0	±0.5	V_d	− 0.09
		C	− 0.14
		Rad. vel.	+ 2.37

1903, March 21.377. Hour angle W $3^h\ 17^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4237.339	+32.05	4371.368	+31.00
40.014	31.68	76.107	30.02
50.959	33.86	4408.622	27.88
54.505	33.96	27.482	32.50
74.958	30.60	35.184	34.14
88.149	31.88	47.892	31.55
92.370	28.98	79.545	30.72
93.957	27.94	73.031	29.57
40.634	30.60	76.185	31.82
52.931	33.76	94.738	28.95

No. of comp. lines	17	Mean	+31.17
ϵ	±1.9	V_a	−27.35
ϵ_0	±0.4	V_d	− 0.16
		C	− 0.14
		Rad. vel.	+ 3.52

α *BOÖTIS.*

1903, April 15.393. Hour angle E $1^h\ 14^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4236.112	−7.29	4294.272	−8.10
39.952	6.29	4315.121	5.63
45.455	5.86	40.634	8.15
50.945	7.47	52.007	4.55
54.505	7.89	52.931	4.13
74.958	7.08	4408.582	4.35
89.885	6.22	27.482	6.15

No. of comp. lines	17	Mean	−6.37
ϵ	±1.4	V_a	−0.41
ϵ_0	±0.4	V_d	+0.07
		C	−0.14
		Rad. vel.	−6.85

1903, April 17.420. Hour angle E $0^h\ 28^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4202.198	−6.99	4294.272	−5.87
19.516	3.27	4315.095	4.31
36.112	6.94	40.634	6.36
74.958	6.87	52.007	5.86
89.885	6.49	4427.482	8.19

No. of comp. lines	15	Mean	−6.12
ϵ	±1.4	V_a	−1.29
ϵ_0	±0.4	V_d	+0.03
		C	−0.14
		Rad. vel.	−7.52

1903, April 21.397. Hour angle E $0^h\ 45^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4219.516	−1.85	4315.138	−2.64
36.112	1.42	39.731	3.66
39.975	1.98	52.007	0.83
45.455	1.62	52.908	2.83
46.996	2.54	71.368	2.20
50.945	0.35	4404.927	2.50
54.505	1.69	08.621	3.54
74.958	2.81	27.482	2.24
94.301	2.86		

No. of comp. lines	23	Mean	−2.08
ϵ	±0.9	V_a	−3.01
ϵ_0	±0.2	V_d	+0.04
		C	−0.41
		Rad. vel.	−5.46

α *BOÖTIS.*

1903, May 8.366. Hour angle E $0^h\ 28^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4337.216	+3.32	4427.482	+6.16
52.931	7.43	40.429	4.80
95.286	6.75	49.569	2.90
4408.683	4.90	4528.647	4.17

No. of comp. lines	10	Mean	+ 5.05
ϵ	±1.7	V_a	−10.31
ϵ_0	±0.4	V_d	+ 0.02
		C	− 0.41
		Rad. vel.	− 5.65

1903, May 9.369. Hour angle E $0^h\ 15^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4287.566	+6.78	4327.082	+7.00
88.149	5.53	52.908	7.65
94.204	4.54	59.784	3.24
4315.121	4.31	78.419	2.12

No. of comp. lines	—	Mean	+ 5.15
ϵ	±1.7	V_a	−10.44
ϵ_0	±0.4	V_d	+ 0.02
		C	− 0.44
		Rad. vel.	− 5.71

1903, May 16.340. Hour angle E $0^h\ 29^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4206.862	+5.20	4315.095	+5.14
19.580	5.18	27.082	7.00
22.382	6.66	40.634	4.49
40.039	5.52	52.007	7.96
46.996	5.86	53.044	3.17
74.958	7.29	59.784	8.51
94.273	6.29	71.368	8.35
4314.381	4.38	4404.927	6.87

No. of comp. lines	17	Mean	+ 6.12
ϵ	±1.5	V_a	−13.08
ϵ_0	±0.4	V_d	+ 0.03
		C	− 0.41
		Rad. vel.	− 7.34

α BOÖTIS.

1903, May 17.352. Hour angle E $0^h 7^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4206.862	+7.34	4246.998	+8.32
22.381	7.74	50.945	8.18
35.389	8.49	4315.138	6.32
40.014	6.92		

No. of comp. lines	10	Mean	+ 7.61
ϵ	±0.9	V_a	−13.45
ϵ_0	±0.4	V_d	0
		C	− 0.41
		Rad. vel.	− 6.25

1903, May 27.352. Hour angle W $0^h 31^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4198.494	+17.63	4294.273	+13.20
4200.148	13.71	15.138	14.04
02.198	15.12	25.939	16.42
36.112	14.09	52.007	16.12
50.945	15.30	52.935	17.97
54.505	14.87	4404.927	12.32
74.958	14.17	27.482	12.80

No. of comp. lines	12	Mean	+14.84
ϵ	±1.6	V_a	−16.84
ϵ_0	±0.4	V_d	− 0.03
		C	− 2.21
		Rad. vel.	− 4.24

1903, July 21.334. Hour angle W $3^h 52^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4198.494	+18.14	4352.007	+20.53
4236.112	15.44	52.935	23.36
54.505	17.68	83.720	19.90
54.912	18.54	4404.927	19.74
94.273	17.45	27.482	21.47
4314.964	22.23		

No. of comp. lines	12	Mean	+19.59
ϵ	±2.3	V_a	−25.05
ϵ_0	±0.7	V_d	− 0.19
		C	− 0.55
		Rad. vel.	− 6.20

γ AQUILAE.

1902, Aug. 5.368. Hour angle E $0^h 5^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4252.917	+5.15	4369.941	+2.67
60.151	2.13	91.924	4.10
72.114	3.54	95.201	3.21
4339.584	2.56	4415.293	6.32
52.908	5.03	27.420	4.61
63.330	8.93	82.438	1.94

No. of comp. lines	10	Mean	+4.19
ϵ	±2.0	V_a	−5.80
ϵ_0	±0.6	V_d	+0.03
		C	−0.30
		Rad. vel.	−1.81

1902, Aug. 7.327. Hour angle E $0^h 53^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4236.112	+ 6.30	4395.286	+11.40
58.639	5.28	4412.415	11.76
74.958	11.08	03.042	10.24
94.273	7.33	30.582	3.39
4319.030	6.32	73.031	9.04
20.992	8.40	94.548	7.66
39.882	6.42	4522.802	5.04
71.368	7.75		

No. of comp. lines	9	Mean	+7.83
ϵ	±2.3	V_a	−6.61
ϵ_0	±0.6	V_d	+0.05
		C	−0.30
		Rad. vel.	+0.95

1902, Aug. 13.359. Hour angle W $0^h 19^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4206.735	+ 7.88	4333.925	+10.10
45.422	2.83	39.617	7.32
58.477	9.15	52.876	4.89
74.746	11.92	59.654	10.52
85.966	7.62	71.368	3.57
94.204	5.72	91.874	7.24
4320.318	10.13	95.201	9.28
32.867	3.81	4427.420	4.34

No. of comp. lines	12	Mean	+7.27
ϵ	±2.8	V_a	−9.06
ϵ_0	±0.7	V_d	−0.02
		C	−0.30
		Rad. vel.	−2.11

γ AQUILAE.

1902, Aug. 15.325. Hour angle E $0^h\ 21^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4274.958	+ 6.66	4369.941	+ 8.85
88.149	5.73	71.368	3.84
91.630	9.08	95.286	10.91
92.208	9.35	4404.927	8.37
4314.381	6.74	08.495	7.07
20.992	6.24	12.293	5.57
32.867	8.02	15.293	8.08
34.063	8.23	25.827	6.78
39.731	6.97	94.356	6.54
44.597	6.97	4522.691	10.14
52.931	10.22	31.327	9.86
59.784	9.22		
No. of comp. lines	5	Mean	+7.36
ϵ	±1.8	V_a	−9.84
ϵ_0	±0.4	V_d	+0.02
		C	−0.30
		Rad. vel.	−2.76

1902, Aug. 18.361. Hour angle W $0^h\ 42^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4249.890	+ 9.26	4352.908	+11.78
58.477	8.10	79.373	6.51
67.985	11.31	95.286	6.21
94.273	8.11	4412.297	6.52
4314.321	9.10	25.827	8.13
34.063	8.58	82.388	10.17
35.034	7.05	94.452	11.67
39.731	7.66		
No. of comp. lines	14	Mean	+ 8.68
ϵ	±1.9	V_a	−11.02
ϵ_0	±0.5	V_d	− 0.03
		C	− 0.30
		Rad. vel.	− 2.67

1902, Aug. 19.359. Hour angle E $0^h\ 38^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4239.952	+ 8.83	4373.396	+ 9.24
58.510	9.02	95.201	10.10
86.101	7.76	4404.927	10.14
4314.964	10.08	25.879	7.05
20.907	8.12	27.266	14.77
32.867	8.71	30.311	7.17
34.119	7.95	35.321	6.76
39.731	7.67	66.711	6.64
44.597	8.08	69.316	12.33
51.930	8.50	82.338	7.56
55.320	15.29	94.520	7.61
No. of comp. lines	13	Mean	+ 9.06
ϵ	±2.3	V_a	−11.40
ϵ_0	±0.5	V_d	+ 0.03
		C	− 0.30
		Rad. vel.	− 2.61

γ AQUILAE.

1902, Aug. 26.327. Hour angle W $0^h\ 18^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4320.907	+ 7.00	4371.368	+ 8.37
28.080	14.00	79.396	11.64
32.867	11.42	4412.415	9.04
33.971	16.12	25.931	12.12
39.731	12.01	27.482	9.14
44.451	15.18		
No. of comp. lines	12	Mean	+11.46
ϵ	±2.8	V_a	−14.00
ϵ_0	±0.9	V_d	+ 0.02
		C	− 0.30
		Rad. vel.	− 2.82

1903, July 21.382. Hour angle E $0^h\ 39^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4334.063	+0.35	4425.931	−4.81
71.368	−4.73	27.482	5.96
4412.293	1.43	30.356	0.27
22.985	1.15	72.884	2.48
24.457	4.20		
No. of comp. lines	20	Mean	−2.74
ϵ	±2.2	V_a	+0.62
ϵ_0	±0.7	V_d	+0.04
		C	−0.55
		Rad. vel.	−2.63

1903, July 28.423. Hour angle W $0^h\ 45^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4332.867	+1.35	4412.293	+1.56
34.119	0.76	25.827	0.47
52.908	3.17	66.727	5.30
71.368	0.07	72.958	2.47
No. of comp. lines	22	Mean	+1.89
ϵ	±1.7	V_a	−2.36
ϵ_0	±0.6	V_d	−0.04
		C	−0.55
		Rad. vel.	−1.11

1903, Aug. 7.383. Hour angle W $0^h\ 29^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4245.520	+1.70	4412.293	+7.07
4315.209	4.10	25.931	4.00
34.130	5.83	27.420	4.27
71.368	6.45	72.912	7.44
95.286	4.50		
No. of comp. lines	20	Mean	+4.93
ϵ	±1.8	V_a	−6.54
ϵ_0	±0.6	V_d	−0.03
		C	−0.55
		Rad. vel.	−2.19

ε PEGASI.

1902, Aug. 19.408. Hour angle E $0^h 2^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4200.045	+3.50	4344.451	+8.28
19.484	3.06	52.908	8.27
39.952	2.90	58.722	4.54
50.287	5.78	71.368	7.75
54.391	7.60	4404.927	0.27
74.888	5.96	15.293	2.78
82.565	4.75	25.827	4.27
94.273	2.44	27.420	5.89
4305.916	4.18	30.356	4.40
08.081	2.72	61.818	5.90
15.090	2.43	94.452	2.87
20.907	5.00	4522.691	3.91
34.120	2.21	31.052	3.57
37.216	3.25		
No. of comp. lines	11	Mean	+4.39
	ϵ ±2.0	V_a	+1.85
	ϵ_0 ±0.3	V_d	0.00
		C	−0.30
		Rad. vel.	+5.94

1902, Sept. 10.326. Hour angle E $0^h 34^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4219.516	+16.06	4398.217	+14.60
20.509	13.34	4415.293	17.12
43.714	13.07	22.985	14.24
54.505	18.67	25.179	15.17
60.640	17.75	27.482	17.67
64.310	13.43	30.356	18.95
4318.817	19.08	64.875	15.85
20.992	12.43	66.727	15.70
32.980	13.77	71.571	15.83
34.120	10.38	72.884	13.88
52.908	13.85	94.548	15.14
71.368	11.39	4522.802	14.05
92.034	10.91		
No. of comp. lines	14	Mean	+14.85
	ϵ ±2.4	V_a	− 8.23
	ϵ_0 ±0.5	V_d	+ 0.03
		C	− 0.30
		Rad. vel.	+ 6.35

ε PEGASI.

1902, Sept. 11.313. Hour angle E $0^h 49^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4200.129	+13.07	4366.749	+16.48
19.516	13.50	71.368	12.35
29.803	14.53	4400.738	13.63
36.112	10.76	15.293	19.84
50.945	12.48	23.060	14.44
58.477	15.42	94.548	18.48
88.149	15.11	96.676	14.94
4314.430	13.20	4522.871	15.98
25.959	18.23	31.123	14.56
39.416	14.65		
No. of comp. lines	12	Mean	+14.82
	ϵ ±2.3	V_a	− 8.67
	ϵ_0 ±0.5	V_d	+ 0.05
		C	− 0.30
		Rad. vel.	+ 5.90

1903, Aug. 7.430. Hour angle E $0^h 13^m$.

4219.516	−1.19	4412.347	−2.85
46.996	1.56	25.827	+0.47
4332.938	3.18	27.420	0.00
34.120	3.18	66.727	0.81
52.921	+1.58	72.884	−3.02
71.368	−2.54	4528.798	1.39
No. of comp. lines	20	Mean	−1.34
	ϵ ±1.6	V_a	+7.40
	ϵ_0 ±0.5	V_d	+0.01
		C	−0.30
		Rad. vel.	+5.77

1903, Aug. 10 397. Hour angle E $0^h 54^m$.

4318.960	−2.77	4412.347	−2.11
20.992	2.22	22.985	+0.88
34.120	1.80	25.827	0.68
52.923	+4.27	27.482	−1.15
71.368	−1.58	94.602	+1.33
74.002	+0.62		
No. of comp. lines	20	Mean	−0.33
	ϵ ±2.1	V_a	+6.08
	ϵ_0 ±0.6	V_d	+0.03
		C	−0.55
		Rad. vel.	+5.23

ε *PEGASI.*

1903, Aug. 19.417. Hour angle W $0^h\ 10^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4219.516	+3.91	4379.396	+3.28
58.477	7.11	4412.347	6.38
4318.873	7.22	25.879	4.27
32.867	4.64	27.482	2.44
34.120	2.70	45.641	4.32
52.923	8.61	66.727	8.53
71.368	3.16	72.912	5.56
76.107	5.75		
No. of comp. lines 20		Mean	+5.19
ε ±2.0		V_a	+1.97
$ε_0$ ±0.5		V_d	−0.01
		C	−0.55
		Rad. vel.	+6.60

1903, Aug. 27.438. Hour angle W $0^h\ 11^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4219.483	+ 7.25	4412.297	+ 9.12
4318.960	5.41	25.879	8.54
44.591	10.14	27.420	7.93
52.923	9.58	66.727	10.87
71.442	6.90	72.884	8.72
4401.613	7.07	4522.802	9.80
No. of comp. lines 20		Mean	+8.52
ε ±1.5		V_a	−1.82
$ε_0$ ±0.4		V_d	−0.01
		C	−0.55
		Rad. vel.	+6.14

γ *CEPHEI.*

1903, Sept. 3.426. Hour angle E $0^h\ 35^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4220.330	−52.94	4352.908	−46.65
37.240	54.30	59.784	52.35
94.273	51.83	4415.293	42.91
4315.138	50.30	27.420	47.96
52.007	50.52		
No. of comp. lines 20		Mean	−49.97
ε ±3.6		V_a	+12.35
$ε_0$ ±1.2		V_d	+ 0.01
		C	− 0.55
		Rad. vel.	−38.16

γ *CEPHEI.*

1903, Sept. 7.393. Hour angle E $1^h\ 7^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4236.112	−54.7[illegible]	4315.138	−52.26
47.591	54.94	52.007	53.01
50.945	52.07	52.908	47.82
68.016	50.58	4415.293	50.46
94.273	53.57	27.420	55.29
No. of comp. lines 20		Mean	−52.47
ε ±2.2		V_a	+12.15
$ε_0$ ±0.7		V_d	+ 0.01
		C	− 0.55
		Rad. vel.	−40.88

1903, Sept. 8.375. Hour angle E $1^h\ 30^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4236.112	−54.44	4352.083	−52.24
39.952	52.34	52.908	51.47
45.455	52.35	60.801	51.02
92.290	54.30	71.368	52.14
94.273	52.46	4425.827	47.72
4315.138	49.69	27.420	51.22
40.634	51.75	54.953	53.71
No. of comp. lines 16		Mean	−51.92
ε ±1.8		V_a	+12.10
$ε_0$ ±0.5		V_d	+ 0.02
		C	− 0.55
		Rad. vel.	−40.35

1903, Sept. 13.383. Hour angle E $0^h\ 57^m$.

Solar Wave-L'gth	Velocity	Solar Wave-L'gth	Velocity
4425.827	−48.65	4776.185	−50.19
54.953	52.84	4522.871	50.05
66.727	50.69	25.314	54.09
73.031	52.17	36.158	53.89
No. of comp. lines 17		Mean	−51.57
ε ±2.0		V_a	+11.75
$ε_0$ ±0.7		V_d	+ 0.01
		C	− 0.55
		Rad. vel.	−40.36

SUMMARY OF RESULTS.

α Persei	
1902	
Oct. 25	−3.58 km
26	2.21
31	3.48
Nov. 6	3.42
8	4.03
15	3.90
26	0.38
Dec. 19	2.11
1902.86	−2.89 ± 0.4 km

α Boötis	
1903	
April 15	−6.58 km
17	7.52
21	5.46
May 8	5.65
9	5.71
16	7.34
17	6.25
27	4.24
July 21	6.20
1903.36	−6.07 ± 0.4 km

ε Pegasi	
1902	
Aug. 19	+5.94 km
Sept. 10	6.35
11	5.90
1903	
Aug. 7	5.77
10	5.23
19	6.60
27	6.14
1903.24	+5.99 ± 0.2 km

β Geminorum	
1903	
Jan. 31	+3.71
Feb. 13	3.12
22	3.55
24	3.55
Mar. 2	3.15
3	3.79
13	3.54
14	2.37
21	3.52
1903.16	+3.37 ± 0.1 km

γ Aquilae	
1902	
Aug. 5	−1.81
7	+0.95
13	−2.11
15	2.76
18	2.67
19	2.61
26	2.82
1903	
July 21	2.63
28	1.11
Aug. 7	2.19
1902.91	−1.98 ± 0.4 km

γ Cephei	
1903	
Sept. 3	−38.16
7	40.88
8	40.35
13	40.36
1903.68	−39.94 ± 0.6 km

Earlier determinations at Pulkowa of the velocity of γ *Cephei* were as follows:

1897, September	9	−51.9 km
	10	50.4
	11	49.8
1898, August	24	47.4

If a different choice had been made of the wave-lengths from Rowland's table, the following differing values of the radial velocities would have been obtained for three of the stars:

β Geminorum	+ 5.37 km
α Boötis	− 5.25
γ Cephei	−37.90

The following table gives the wave-lengths of the lines in the stellar spectra, corrected only for the Earth's motion. *n* denotes the number of spectrograms on which the particular line was measured:

α PERSEI.

λ	n	λ	n	λ	n
4202.226	5	4294.228	5	4374.816	2
15.650	4	99.270	2	76.116	3
26.825	6	4300.209	3	83.672	6
36.024	5	08.022	7	95.211	2
46.998	2	14.306	7	4404.895	8
50.893	8	15.160	3	50.673	3
54.479	7	20.962	4	64.657	3
58.328	5	25.894	3	81.409	3
71.920	5	40.654	2	4501.462	3
88.068	2	51.957	8	22.885	2

β GEMINORUM.

λ	n	λ	n	λ	n
4185.144	6	4254.598	7	4359.847	6
88.010	2	68.153	2	70.004	2
99.354	3	75.050	2	71.415	5
4200.185	5	86.231	2	76.158	3
19.611	7	88.192	2	83.796	3
22.448	5	92.373	2	4404.934	8
36.223	5	94.353	4	08.628	2
37.369	2	4314.454	5	15.386	8
39.112	4	15.230	5	27.500	5
40.077	10	37.335	2	35.314	2
45.550	7	40.700	7	59.381	2
47.063	5	52.092	7	69.635	2
47.686	6	53.011	8	73.064	2
50.353	3	58.944	3	73.273	2
51.028	8				

α BOÖTIS.

λ	n	λ	n	λ	n
4198.455	2	4250.888	5	4351.938	6
4202.131	2	54.435	5	52.892	8
06.787	2	74.860	6	59.690	2
19.449	4	89.775	2	71.287	2
22.289	2	94.169	7	83.677	3
36.017	5	4315.014	8	4404.860	6
39.897	4	25.923	2	08.542	4
45.371	2	(37.040)	3	27.393	8
46.905	3	40.514	3	69.524	2

γ AQUILAE.

λ	n	λ	n	λ	n
4219.387	2	4332.823	5	4404.871	3
36.012	3	34.042	8	12.277	9
39.885	2	39.609	6	15.211	6
45.388	2	44.520	3	25.817	9
46.886	2	52.903	6	27.359	8
50.798	2	59.721	2	30.280	3
58.454	4	69.905	2	66.675	3
74.901	3	71.314	9	72.827	5
94.218	3	79.339	3	82.340	3
4314.310	2	91.868	2	94.419	3
20.901	4	95.235	7	22.615	4

ε PEGASI.

λ	n	λ	n	λ	n
4200.151	2	4333.005	4	4415.408	3
19.582	6	34.172	6	23.096	3
20.487	2	37.285	1	25.939	8
36.106	3	44.650	2	27.536	7
45.434	1	53.043	6	30.490	4
47.073	1	71.425	8	66.826	7
58.561	3	76.214	1	72.977	4
74.994	1	83.739	1	94.640	4
88.236	1	4400.806	1	4522.888	5
4318.972	5	04.952	1	28.755	3
21.030	3	12.377	7	31.167	2

γ CEPHEI.

λ	n	λ	n	λ	n
4219.751	1	4314.574	3	4454.331	2
35.504	2	40.051	1	66.138	1
36.639	1	51.448	3	70.680	1
39.374	1	52.371	3	72.419	1
44.877	1	59.194	1	75.602	1
46.977	1	70.776	1	4522.285	1
50.371	1	4414.776	2	24.667	1
67.460	1	25.284	2	28.251	1
91.676	1	26.832	3	35.513	1
93.687	3				

Pulkowa,
January 1904.

THE SPECTRA OF MIXED GASES.

By P. G. NUTTING.

EARLY in spectroscopic work it was observed that mixed gases, electrically excited, frequently gave the spectrum of a heavy metallic component more strongly than that of a lighter component. In 1878 E. Wiedemann[1] described experiments with mercury and sodium in hydrogen and nitrogen. He proved that the intensities of the metallic spectra were out of all proportion to the relative amounts of metallic vapor present. It is a matter of common experience, in preparing Plücker tubes to exhibit metallic spectra, that as soon as the tube is heated sufficiently to vaporize the contained metal, the spectrum of the lighter gas filling the tube disappears. Recently Professor Percival Lewis has shown[2] that when mercury vapor is present in a tube of hydrogen, it will reduce the hydrogen spectrum to about half its original intensity when but one molecule of mercury to three thousand of hydrogen are present. It is well known that the cadmium spectrum will swamp that of hydrogen long before the cadmium is even melted. The red lines of the two spectra are equal at a temperature of about 200° C.

At first thought, we should say in explanation that the vapor of a metal would be a better electrical conductor than that of a non-metal and, carrying the most of the current, would show the brightest spectrum. But this hypothesis is clearly untenable. Although gas conductivities have not yet been accurately determined nor yet even defined, it is well known that, under the same conditions, metallic vapors do not differ widely from non-metallic vapors and the permanent gases in conducting power. And even then, why should the vast majority of lighter molecules be left idle as soon as a few of the heavier molecules are present?

[1] *Wied. Ann.*, **5**, 500–524, 1878.

[2] ASTROPHYSICAL JOURNAL, **10**, 137–163, 1899; *Annalen der Physik*, **2**, 447–458, 1900.

Taking up the problem at this point, it was quickly shown that metallic character has little, if anything, to do with spectral predominance. Sulphur and iodine are nearly as effective in swamping hydrogen and nitrogen as are mercury or cadmium. Further, a non-metallic vapor may swamp a metallic. This was shown by a combination of sodium with bromine and iodine vapors. Iodine was found to be much more effective than chlorine, and this suggested that atomic weight might be the ruling factor. Even the persistent mercury spectrum may be displaced by the slightly heavier thallium, iodine easily swamps chlorine and sulphur, while any of the heavier metals displace sodium, itself so persistent in lighter gases. In all, about eighty combinations of the fifteen available vaporizable elements were tested without any contradictions to the atomic weight law being discovered; but several combinations, like cadmium and indium, oxygen and nitrogen, of elements of nearly equal atomic weight, would require a more accurate determination of relative pressure and spectral energy to be used in evidence. The law may be stated thus: In the spectrum of a mixture of gases, other things being equal, *the spectrum of the gas of greater atomic weight will be brighter.* This applies to such simple, moderate, fairly homogeneous excitation as we have in a Plücker tube containing gases under a pressure of from 0.1 mm to 10 mm, carrying a current of not more than 10 milliamperes. Outside these limits, the atomic weight effect is always less, *i. e.*, the intensities of the spectra are more nearly in proportion to the relative amounts of the gases present. In the luminous portions of the arc and spark, conditions of pressure, current density, etc., are so complex that a test is almost hopeless.

The greater part of the work here described was done with small Plücker tubes excited by a 2,000-volt alternating current. Sometimes a small induction coil was used. Tests of easily vaporizable substances were repeated with tubes having external electrodes. Other tests were repeated with small electrodeless tubes excited by electric waves from a Seibt quarter-wave resonance apparatus. It is hoped soon to carry the work much further by using this apparatus to excite tubes of quartz in

which even silver and copper may be vaporized. Spectra were examined with a small direct-vision spectroscope; on account of the greater ease in identifying and comparing spectra, a low dispersion is preferable. Except in a few instances, the effects to be observed were so pronounced that no accurate photometry nor measurements of the relative amounts of gases present were necessary. Sometimes the two spectra were brought to equality and relative pressure estimated, and sometimes the tube was filled with nearly equal quantities of the two vapors and relative spectral energies estimated. A list of the tests made is given below. A parenthesis indicates that more accurate measurements are necessary to decide spectral predominance for equal proportions.

Atomic Weight	Element	*Tl*	*Hg*	*I*	*Te*	*In*	*Cd*	*Br*	*Se*	*Zn*	*Cl*	*S*	*Na*	*O*	*N*
1.......	*H*	+	+	+	+	+	+	+	+	+	+	+	+	?	+
14.......	*N*	+	+	+	+	+	+	+	+	+	(+)	+	+	(+)	
16.......	*O*	+	+				+				(+)	+	+		
23.......	*Na*		+	+	+	+	+	+	+	+	+				
32.......	*S*	+	+	+	+	+	+	+	+	+	(+)				
35.......	*Cl*	+	+	+			+	+							
65.......	*Zn*	+	+				+								
79.......	*Se*	+	+	+		+	+								
80.......	*Br*	+	+	+			+								
112.......	*Cd*	+	+	+	+	(+)									
114.......	*In*	+	+												
125.......	*Te*														
127.......	*I*	+	+												
200.......	*Hg*	(+)													
204.......	*Tl*														

In addition to these results may be cited the work of Collie and Ramsay[1] on mixtures of argon and helium. They found that a little argon mixed with helium showed the spectrum of the former strongly, while a small percentage of helium in argon showed but a faint helium spectrum.

Chemical combination occurs in the vast majority of cases, but compound spectra occur only in the case of a few halides. If we start with, say, hydrogen and sulphur, vaporize the sulphur while the discharge is passing, then allow the tube to cool, we

[1] *Proc. R. S.*, **259**, 57–270, 1896.

get no spectrum other than those of hydrogen and sulphur during the process and no trace of H_2S on opening the tube. The result is the same when we fill the tube with H_2S at the start, and similarly with black mercury sulphide, except that a heavy deposit of sulphide remains. Even with the cadmium-oxygen combination, where the product cannot be kept vaporized, the two spectra may be observed superposed during combination. But with the mercury halides a strong band appears, brighter even than the mercury spectrum. The halogen spectrum remains visible as well as the mercury, evidently in proportion to the atomic weights of these substances, but the compound spectrum is brighter than either, possibly in proportion to the molecular weight of the compound. It would be in accord with theory if the spectra of compounds followed a molecular weight law, but observations yet made are far too meager to establish it. Varying the pressure over quite a range does not generally affect the preponderance of one spectrum over another. But at very high or very low pressure the spectrum of the lighter gas is stronger in proportion than at intermediate pressures. Changes in temperature have little effect so long as all components and products remain vaporized.

Changes in current density over quite a wide range do not affect the spectral preponderance. But an excessive current density was found to increase the relative intensity of the lighter gas in every case observed. This test was made with some special Plücker tubes having a third bulb in the middle of the capillary. Though the central bulb had several hundred times the cross-section of the neighboring capillary, the spectra of the two portions never differed greatly. But a large tube with large bulbs and very fine capillary, filled originally with damp hydrogen, after considerable use showed a nearly pure hydrogen spectrum in the capillary, but a nearly pure oxygen spectrum (evidently from decomposed water vapor) in the bulbs. When the gas pressure in an ordinary Plücker tube is so great that a condenser in shunt alters the form of the discharge, say at 2 to 12mm, the effect of the capacity is invariably to intensify the spectrum of the lighter gas, *i. e.*, to oppose the effect of greater

atomic weight. It is very difficult to exhaust a mercury tube so thoroughly, even if the mercury be kept boiling for a long time, that the air or hydrogen lines will not show with a condenser in parallel.

Frequently one spectrum will swamp the nearest lines of the second spectrum first. This effect is most marked in combinations of some metallic vapor with nitrogen or a halogen. Combinations with the sulphur group, however, show no trace of this effect. Thallium appears to weaken the *distant* (red) oxygen lines most.

No attempt at quantitative work has been made, nor any attempt to establish a quantitative relation between spectral preponderance and atomic or molecular weight. Judging by the work here, relative spectral energy might well be proportional to atomic weight; it certainly is not less, but may well be more than proportional.

In conclusion, it may be well to call attention to the simple explanation of the observed phenomena afforded by modern electron theory. Consider a current consisting of a convection of charged particles. Consider luminous and ultra-violet radiation as due to vibrations of the electrons within the atom. Excitation would be due to the impact of electrons, largely negative. The larger atoms would not only be hit most frequently, but would shield the smaller atoms from impact by the negative electrons. At very low pressures the shielding action would be less in proportion. Irregular heat motion would have little effect on either total or relative excitation. Increasing the current would increase the number of exciting electrons in proportion. The relative excitation (of large and small atoms) would remain unchanged, while the total excitation would be proportional to the current. While with moderate currents probably but a single electron is torn from an atom, excessive currents might still further break up the atom, and so produce a more and more continuous spectrum. In the rare instances of molecules so stable as to withstand having a fourth of their charge suddenly torn away, the electrons in the combined atoms would still be able to vibrate, but with altered and greatly damped

vibrations. The large molecules would receive greater excitation than any atoms present. Hence compound spectra, when they do occur, are banded and relatively intense. Oscillating discharges would excite the smaller atoms relatively more than continuous currents.

If the exciting negative electrons are all alike, no matter from what atoms they are torn, one cannot properly speak of the current being carried by one gas of a mixture more than by another. Distribution of spectral energy would not then be a matter of distribution of current.

NATIONAL BUREAU OF STANDARDS,
Washington, December 1903.

ON DOUBLE REVERSAL.

By H. Konen and A. Hagenbach.

In his interesting article on double reversal in the October number of this Journal,[1] Humphreys finds that in general every double reversal is an apparent one and is occasioned by secondary influences, such as superposition of different orders, broadening, the simultaneous action of several sources of light, etc.

In view of the small number of observers whose results on this subject have been so far published, it will perhaps be of service if we describe some of the material that we find on our photographs, which leads us to almost the same conclusions that Humphreys reaches. The fact that our observations for the most part refer to the same lines as those of Humphreys has not led us to suppress this note, because the comparative infrequency of the phenomenon and its limitation to a rather small number of lines seem to indicate that just these lines are the only ones that can come into consideration in observations of multiple reversal.

We state in advance that, in agreement with Humphreys, and in contradiction to Liveing and Dewar,[2] we have never been able to observe double reversals visually in a simple arc.

We classify multiple reversals as apparent, real, and doubtful. Aside from the case of two arcs given by Humphreys, we observe five sorts, as follows: (1) superposition of two lines of different orders in grating spectra; (2) superposition of emissions which are not simultaneous; (3) action of different portions of the source of light; (4) superposition of lines of the same order; (5) unsymmetrical or symmetrical reversal combined with broadening.

We can cite, as examples of (1), among others, the magnesium line at λ 2852.25, in addition to those given by Humphreys. This coincides approximately in the second order with the *Mg* line at λ 5711.56. If the first is markedly widened, a bright line is seen

[1] Astrophysical Journal, **18**, 204–210, 1903.

[2] *Proceedings of the Cambridge Philosophical Society*, **4**, 256–265, 1882.

unsymmetrically situated in the reversal. Fig. 1 of Plate XIV is a reproduction of a portion of such a reversed line, together with the line at λ 5711.56. It is, of course, self-evident that in every apparent self-reversal of the first kind the components can be resolved by a separation of the orders.

Examples of (2) can be readily observed in the higher orders of grating spectra. Humphreys describes the appearance for the silver line at λ 3383.00. We cite among them the iron lines at $\lambda\lambda$ 3720.08, 3735.02, 3737.28. These lines were first photographed in the third order over the whole plate when there was but little iron in the arc; then the edges of the plate were covered and one of the carbons was replaced by an iron pole. The result is a series of apparent doubly reversed lines, the parts of which were, however, emitted at different times. It is illustrated in Fig. 2, where the first emission is seen below, and the superposition of the two above. A further illustration is given by the two D lines in Fig. 3, which was obtained with a small grating during an exposure of the red portion of the iron spectrum. No double reversal could be seen visually during the rather protracted exposure, but the appearance of the D lines doubtless constantly oscillated between relative sharpness and self-reversal.

The cases named under (3) and (4) we shall treat together, as they cannot be separated with certainty. The first surely cannot be excluded on *a priori* grounds, when we recall the actual differences in the spatial distribution of the emission of the arc, and when we consider that we either simultaneously illuminate each point of the slit with rays coming from different parts of the arc, or, in case an image of the source is projected upon the slit, we employ different parts of the arc on account of its motions. The astigmatism of the grating must also be taken into account. The possibility under discussion will particularly arise if other lines of the same element in the same order are also seen simultaneously in the reversal or double reversal. But then the *Auffassung* is different in each case.

Humphreys finds the iron line λ 3092.87 is a reversal of the aluminum line at λ 3092.84, and he explains this apparent double

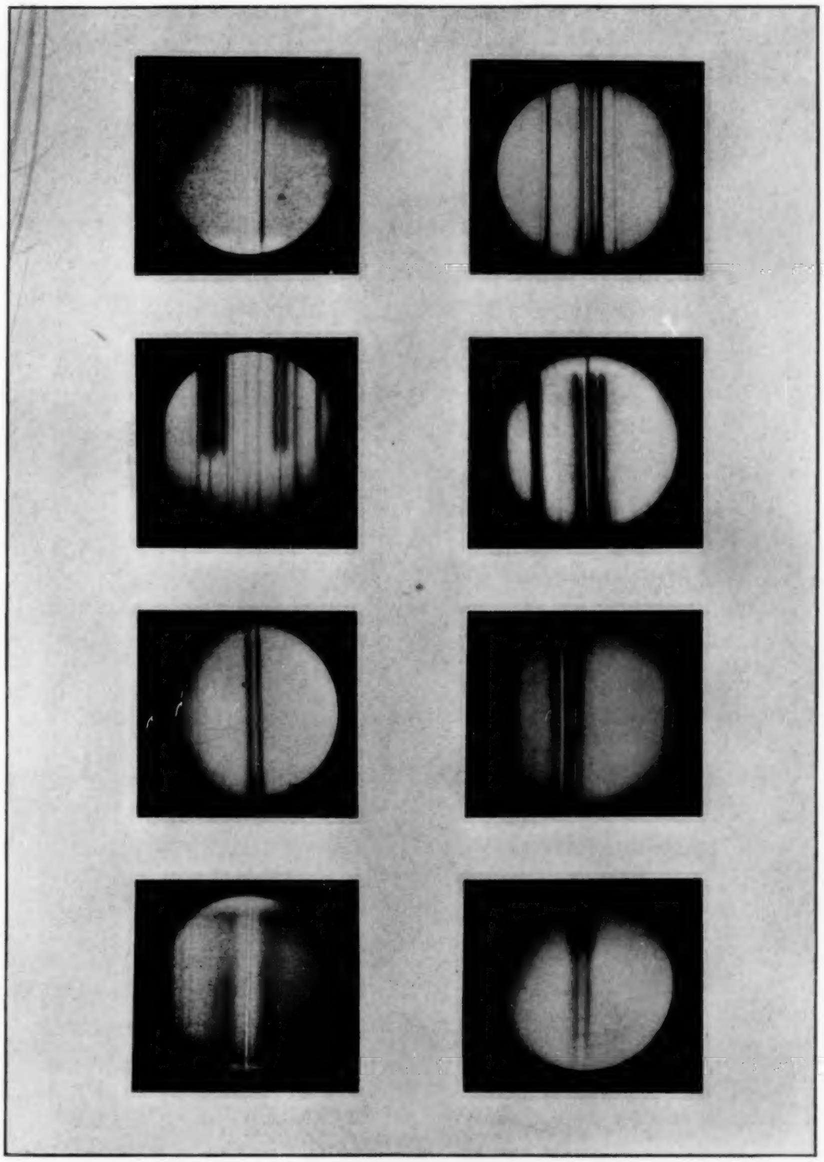
PLATE XIV.

1 5

2 6

3 7

4 8



Double Reversal.

reversal on the assumption that the cooler aluminum vapor in the outer parts of the arc absorbs the light of the radiating nucleus, but not that of the iron vapor, since the emission of the two metals overpowers the absorption of the aluminum vapor.

We find a similar case with the magnesium line at λ 2852.25, in the broad reversed center (total width about 85 tenth-meters, of the reversal 17 tenth-meters) of which may be seen the two bright magnesium lines at $\lambda\lambda$ 2846.9 and 2848.5, in addition to a second reversal (of width about 2 tenth-meters). See Fig. 4, Plate XIV.

In this case the arc was projected upon the slit by a lens. But the effect of an action of the different parts of the arc does not seem to us excluded by that fact, although it must be admitted that this view is somewhat artificial. This is also true when we attempt to apply Humphreys' explanation to this case, as we must then assume that the absorptive power possessed by the magnesium vapor on account of its emission lines at $\lambda\lambda$ 2846.9 and 2848.5 is of a different order from that pertaining to the wave-length 2852; that is, we should have to designate the lines $\lambda\lambda$ 2846.9 and 2848.5 as "short" in the sense that term was used by Lockyer. Now, the last two belong to the series lines, while λ 2852 does not; but, in view of the circumstance first mentioned, we cannot regard such an assumption as permissible without further facts. The reasoning, which evidently can be easily expressed with the aid of Kirchhoff's law, can also be applied to the example given by Humphreys. We nevertheless prefer to leave open the question as to which of the two possibilities has the greater probability.

We name as examples of the fifth sort of apparent double reversal the lines $\lambda\lambda$ 3021.19, 3027.76, 2973.41, and 2973.17, already cited by Humphreys, but repeatedly observed by us before we had known of his paper. As to the last two lines, reproduced in Fig. 5, we have nothing to add to the description by Humphreys; but we find the details in case of the lines at λ 3021 a little different from his description. Fig. 6 pictures the three lines at $\lambda\lambda$ 3021.19, 3020.76, and 3020.62 with an average amount of vapor. The plate was taken in the third order, and,

as a consequence, the line at λ 4531.33 in the second order falls between λλ 3020.76 and 3021.19, as may be seen at the lower part of the figure where the orders are separated. With greater quantities of vapor the line at λ 3020.76 broadens out particularly, and an apparent, unsymmetrical, double reversal results from the absorption of the common edge of the lines at λλ 3020.76 and 3020.62 (Fig. 7). A further example of this sort of double reversal is given by the cadmium lines at λλ 3467.76 and 3466.33.

We believe that we meet with a true double reversal in case of the magnesium line at λ 2852.25. If a large piece of magnesium is inserted in the arc, or if magnesium rods are employed as poles, the magnesium will begin to burn at a particular moment. If the arc is now extinguished and then quickly relit, a large amount of magnesium vapor develops explosively, and bursts out from the arc. A plate was taken with a small concave grating at just this moment, with a very short exposure, less than one-half second. This time was fully sufficient for obtaining a distinct and fully exposed plate, but an exposure of one-fourth second proved to be insufficient. All plates taken under these circumstances show the *Mg* line at λ 2852 as immensely broadened and multiply reversed.

None of the cases mentioned hitherto seems to be involved, for, in view of the briefness of the exposure, which represents the lower limit, the action of successive stages of emission may be presumed to be excluded. The regularity of the process further precludes the accidental effect of different parts of the arc. The conditions are evidently literally the same as those described by Liveing and Dewar,[1] and hence we do not doubt a true multiple reversal is obtained in this experiment.

The objection could be made that during the short exposure the arc was repeatedly lighted, so that we had the case studied by Humphreys. But absolutely nothing of the sort could be seen, if two separate circuits are required. If it should nevertheless be assumed that the two arcs might be fused into one, then our case does not in fact exclude that possibility. But in

[1] *Loc. cit.*

that event we see no difference from the old view, which assumes different strata of emission and temperature.

We find on our plates a number of other double reversals, but we cannot give the eonditions necessary to their production, and we therefore would designate them as doubtful, Instances are the D lines; *Ag* 3383.00, 3280.80; *Al* 3961.68, 3944.16, (both together, Fig. 8).

Otherwise we agree with Humphreys that the majority of the double reversals observed on photographs are only apparent, but we think that genuine cases do occur and that this happened in the instance given by Liveing and Dewar.

UNIVERSITÄT BONN,
December 1903.

ON THE WAVE-LENGTH OF THE CADMIUM LINE AT λ5086.

By Charles Fabry.

In their beautiful investigation on the absolute values of wave-length, Michelson and Benoit[1] measured the wave-lengths of several of the lines of cadmium. They obtained for the ratio of the wave-lengths of the red line at λ6438 and the green line at λ5086 the value 1.2659644.

On measuring the same ratio, Hamy[2] found the sensibly different value of 1.26594487. Regarding the wave-length of the red line as fixed,[3] that would correspond to a discrepancy of 0.0784 tenth-meter for the green ray, or relatively to an error of 15 millionths.

This decided divergence has attracted the attention of several spectroscopists,[4] and seems to have thrown some doubt either upon the accuracy of measurements by the interference method or upon the invariability of the standard of wave-length derived from the spectrum of cadmium. An attentive reading of M. Hamy's papers ought to show clearly enough the cause of the discrepancy: the green line measured by Hamy *is not the same* as that observed by Michelson and Benoit. Meanwhile, on account of the importance of this question to spectroscopy, I have thought I ought to undertake a detailed examination of the matter.

I must remind the reader that M. Hamy employed a tube of cadmium vapor *without electrodes*, fed by an induction coil with a condenser in parallel. M. Michelson used a tube with electrodes. Hamy's tube gave a more complex spectrum than did Michel-

[1] *Travaux et Mémoires des Bureau International des poids et mesures*, Tome 11.

[2] *Comptes Rendus*, **130**, 490, 1900.

[3] M. Hamy has verified the perfect identity of the wave-length of the red line given by his tube with that given by Michelson's tube. *Comptes Rendus*, **130**, 700, 1900.

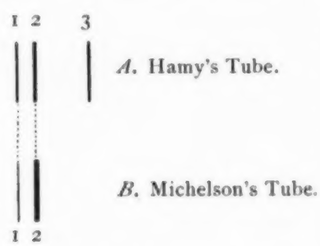
[4] Louis Bell, Astrophysical Journal, **15**, 157, 1902; *ibid.*, **18**, 191, 1903. J. Hartmann, *ibid.*, **18**, 187, 1903.

son's, which yielded only the *arc lines*, or the other lines only very feebly, while Hamy's tube showed the *spark lines* besides.

I then examined the line at λ5086 produced by an Hamy tube by the powerful spectroscopic method devised by M. Perot and myself, which is based on the employment of fringes from silver films. I found that the line is a triplet, having the appearance shown in Fig. 1, *A*. This result is in perfect accord with that found by Hamy, as shown in the following paragraph from one of his notes:[1]

> The ray at λ508 emitted by my tubes without internal electrodes is triple. Under the conditions of my experiments, that radiation is composed of one simple line and a pair of equal intensity. My measures refer to the simple line, which is the least refrangible of the three composing the group.

It thus appears that the line measured by Hamy is certainly the one numbered 3 in Fig. 1. I found, moreover, that the relative intensities of the three components are very variable, but the study of that question would lead us beyond the subject in hand. I shall probably have occasion to return to it later.



Wave-lengths increase toward the right.
Scale about 10 cm to the tenth-meter.
FIG. 1.

The same radiation, on the other hand, given by Michelson's tube is a double, composed of two very unequal lines, as seen in *B*, Fig. 1. I have assured myself of the perfect coincidence of these two lines with 1 and 2 (Fig. 1, *A*) given by Hamy's tube. Line 2 is much the more brilliant in Michelson's tube. I have often found line 3 excessively faint. It is certain it was line 2 which was measured by Michelson and Benoit.

There would therefore have been good ground for surprise if the two series of measures had led to the same result.

I have measured directly the interval between lines 2 and 3, and find a difference of 0.076 tenth-meter, which establishes an agreement (at least to three ten-millionths) between the values of Hamy and of Michelson.

[1] *Comptes Rendus*, **130**, 700, 1900.

From the existence of these close and variable lines, it is certain that the line is not at all suitable for serving as a standard. I would remark here that no confusion is possible, if a little care is taken. The method of fringes from silver films permits the separation of the closest lines without any confusion whatever; if an unusual component should be developed, it would be seen at once. I should add that it has never happened in the course of several years of work during which M. Perot and I have constantly employed a Michelson tube. In that tube the principal component of the green line (2 in Fig. 1) is so predominant that the line may almost be regarded as simple.

Hence if it is desirable to preserve as the fundamental standard the red line, which is perfectly simple, there can be no inconvenience in the use of the green line as a secondary standard known with extreme precision.

The appearance and disappearance, according to circumstances, of the satellite lines still remains a most curious fact, the close study of which should lead to interesting results.

Université de Marseille,
December 1903.

ON THE CORRECTIONS TO ROWLAND'S WAVE-LENGTHS.

By C. Fabry and A. Perot.

In his recent article on "The Perot-Fabry corrections of Rowland's Wave-Lengths"[1] Louis Bell recalls, with reason, the fact that the wave-lengths in the solar spectrum may be altered by the radial velocity of the observer, due to the rotation of the Earth as well as to the eccentricity of its orbit. This cause of error was carefully examined during the preparation of our experiments, and we took care to choose our conditions so that it was negligible. But, inasmuch as we omitted to call special attention to this point in our memoir, it will not be superfluous for us to give a few points on the subject.

Although the preparation for our experiments consumed a year, the definitive measures were made between June 25 and July 6, 1901. The Earth having been at aphelion on July 4, the velocity[2] of the center of the Earth with respect to the Sun varied between +0.08km and −0.02km. The corresponding correction for wave-length 6000 changes from +0.0016 to −0.0004 tenth-meters. Furthermore, the observations were made between 10:30 A. M. and noon, and the radial velocity due to the diurnal motion varied between −0.12km and 0, to which corresponds a correction of from −0.0024 tenth-meter to 0.

The two corrections are separately negligible, and are almost always of opposite sign. The largest total correction does not attain a relative value of 4 ten-millionths. It should be further remarked that each line was measured several times on different days and at different hours, whence the errors, in any case so small, could not but be eliminated in the mean.

In an interesting article published in this Journal,[3] Hartmann has remarked that our curve of corrections to Rowland's values

[1] Astrophysical Journal, **18**, 191, 1903.

[2] Computed by the formulæ given by Frost, Astrophysical Journal, **10**, 283, 1899.

[3] "A Revision of Rowland's System of Wave-Lengths," **18**, 167, 1903.

was not applicable to the metallic lines. We ought to state expressly here that our curve, deduced solely from observations in the solar spectrum, does not apply to any wave-lengths of that spectrum except as they are given in Rowland's "Preliminary Table." As to the numerical values of Rowland, relative to the metallic lines, the fact is known that the results of the measures have undergone modifications[1] which without doubt render it difficult to adopt systematic corrections. Hartmann's discussion seems to confirm that view. It would no doubt be a useful piece of work to compare a certain number of metallic lines with those of the solar spectrum, the wave-lengths of which are now known at least to about one-millionth.

The corrections which we have found for the Rowland values have the effect, not only of causing the disappearance of the errors in the relative wave-lengths, but also of correcting them absolutely, so as to make them accord with the absolute values of the cadmium wave-lengths found by Michelson and Benoit. It is evident that if it was desired solely to correct the values relatively, without considering the absolute values, smaller corrections could be used than those we have given. This is what Hartmann proposes to do: the curve of corrections which he has calculated, a simple transformation of ours, is obtained on the basis of departing from a unit of length so chosen that the positive and negative corrections will be equally divided. That amounts to taking a new unit of length slightly different from that of the metric system. From the point of view of astrophysics alone, the choice of the unit of length is certainly a matter of indifference, but this is not the same for other applications. It would be annoying that one and the same wave-length should be represented by two numbers according to the application that is in view. Consequently it seems difficult to regard the solution proposed by M. Hartmann as other than provisional.

UNIVERSITÉ DE MARSEILLE,
CONSERVATOIRE DES ARTS ET MÉTIERS, PARIS,
December 1903.

[1] On this point see HARTMANN, *loc. cit.*, p. 170; ROWLAND, *Memoirs of the American Academy*, **12**, 116, 189; JEWELL, ASTROPHYSICAL JOURNAL, **3**, 89, 1896.

PHOTOGRAPHIC OBSERVATIONS OF COMET 1903 *c* (BORRELLY).[1]

By SEBASTIAN ALBRECHT.

THIRTY-SIX negatives of Comet 1903 *c* (Borrelly) were secured between June 22 and August 18 inclusive, with the Crocker telescope, the Pierson camera, and the Floyd camera.[2] The original negatives were taken by Mr. R. H. Curtiss and myself, except on two nights when both were engaged in other work, and Mr. J. D. Maddrill kindly made these exposures for us. Table IV contains a list of the negatives. The smaller light-ratio of the Floyd telescope rendered the five plates taken with this instrument less suitable for measurement, and hence measures of these are not included in the tables.

Two distinct types of tails persist throughout the entire series of photographs. The principal tail is long and straight in its general direction, and in a large number of cases can be traced to the edge of the plate, a distance of 10°. It developed some very interesting forms, changing its aspect completely from day to day. Several more or less permanent features of the main tail deserve special mention. Its length was always considerable, and it was directed almost exactly away from the Sun. The deviation from the radius vector, which was negative before the middle of July, became positive after the Earth passed through the plane of the comet's orbit; in both cases, however, indicating a lag behind the radius vector. The main tail, in general, widens out after leaving the head, and on a large number of plates divides into two distinct branches. From measures of the angle between these two branches of the main tail on eight plates, the mean angular distance between them was found to be about 7°. There is a marked contrast in the appearance of the primary tail on the negatives taken in July and on those taken in August. The tail on the plates of July is, with three exceptions

[1] Also to appear as a *Bulletin* of the Lick Observatory.

[2] For descriptions of these instruments see *L. O. Bulletin* No. 42, and *Pub. A. S. P.* 7, 162, 1895.

which will be mentioned later, smooth and continuous, while on the August plates it is twisted and full of condensations, indicating greatly increased activity as the comet approached perihelion. The accompanying illustrations show this feature very well.

The other tail is short and very much curved, and presents practically the same appearance on all the negatives. It is bright even on the plates of June. Its length is about 1°.5. On the plate of June 22 it made an angle of 26° with the primary tail. This angle gradually diminished, owing to the foreshortening produced by the Earth's approach to the plane of the comet's orbit, until about the middle of July, when the two tails appeared to coincide. After the passage of the Earth through the plane of the orbit, the angle again increased until August 18, when it amounted to 33°.

In addition to these two tails, occasional streamers developed, some of which branched off from the main tail, while others issued directly from the head. Some of these were of a more or less persistent nature, and in general they were narrow and straight. Their length varied somewhat, a part of the variation being probably due to unequal exposures. The following table illustrates the persistent nature of these streamers:

TABLE I.

Principal Streamers Issuing from the Comet's Head.

Plate	Date	Streamers Preceding t	Streamers Following t
11	July 16	....	5°.5
12	July 17	....	Not on plate
13	July 17	....	7.5
14	July 18	....	Not on plate
15	July 18	....	8.5
16	July 19	7°.0	7.5
17	July 19	7.5	
18	July 20	6.5	
19	July 20	6.0	
27	Aug. 11	5.0	11.0
28	Aug. 12	5.5	10.5
29	Aug. 13	6.5	Several streamers from tail
30	Aug. 14	7.5	9.0
31	Aug. 15	11.0[1]	7.0
32	Aug. 18	7.0 (faint)	8.5 (faint)

[1] One-fourth of a degree from the head this streamer has a sharp bend, and then makes an angle of 8° with t_1.

PLATE XV.

July 23, 9^h 0^m to 14^h 30^m.

July 24, 9^h 0^m to 14^h 30^m.

July 25, 9^h 0^m to 15^h 0^m.

COMET 1903 *c* (BORRELLY).

Three of the negatives, those of July 23, 24, and 26, deserve special mention, on account of unusual structure in the principal tail. The plate of July 23 shows two long masses entirely separated from the main tail at about 3°.5 from the head, and on the side following the radius vector. One of these extends to the edge of the plate, a distance of about 10° from the head. The main tail extends to a distance of about 5° from the head, and a long, narrow streamer leaves it about 2° from the head. These four branches, together with two prominent bands in the main tail near the head, all making small angles with the general direction of the tail, present a wave-like appearance. The entire main tail somewhat resembles a rope, one end of which is unraveled and which has two of the loose strands severed.

The plate of July 23 shows, in addition, an entirely new tail issuing from the head in advance of the radius vector, preceding it by 6°, but being bent toward the radius vector shortly after leaving the coma. This tail assumes the forked characteristic which the main tail shows on a majority of the plates. Its angular width is 4°.6, and on the original negative it can easily be traced to a distance of 4° from the head. The plate of July 24 does not record this extra tail. The plate of the 24th shows a detached section, preceding the radius vector, which is composed ot two distinct portions, the shorter being nearer the head and pointing directly toward it. This plate also records a detached streamer on the following side of the main tail, and directly opposite the detached section referred to above. The interval from the 23d to the 24th of July was evidently one of unusual activity. The plate of July 25 shows no unusual forms. The plate of July 26 shows the main tail broken at a distance of about 3°.5 from the head. (This plate is difficult to reproduce.)

I have made measures of the plate of July 24, and of the reproductions of plates of the same date made by Barnard and Wallace at the Yerkes Observatory, and one by Quenisset at Nanterre. The measures were made on the end of the section nearest the head, and the times used were the beginnings of the exposures. This seems to be the most reasonable assumption regarding the time to be used for purposes of comparison of the

different plates, as there is very little doubt that the extreme near end of this impression was made within a few minutes of the beginning of the exposures, and that during the exposures the section receded from this point. Although the beginning of the exposure does not correspond exactly to the first impression on the plate, the plates will be comparable (if we disregard the effect of the different light-ratios of the lenses with which the negatives were taken), no matter what the duration of the exposures may be. In the tables N stands for the Nanterre photograph, Y_1 and Y_2 for the first and second Yerkes photographs, and L for the Lick photograph.

TABLE II.

Plate	Beginning of Exposure, G. M. T.	Distance of Near End of Section from Head
N	$11^h\ 00^m$	$1°\ 39'$
Y_1	14 57	2 19
L	17 00	2 50
Y_2	17 59	3 2

TABLE III.

Plates	Time Interval	Hourly Rate	Velocity of Recession	
			Miles per Second Relative to Head	Miles per Second Relative to Sun
N and Y_1	$3^h\ 57^m$	$10'.1$	28	6
N and L	6 00	11.8	33	11
N and Y_2	6 59	11.9	33	11
Y_1 and L	2 3	15.1	42	20
Y_1 and Y_2	3 2	14.2	39	17
L and Y_2	0 59	12.2	34	12

The discordances in the above rates of recession are probably partly due to unavoidable uncertainties of measures on such objects, and partly to the different light-ratios of the lenses with which the negatives were secured. They differ somewhat from those obtained by Barnard, but this must be expected on account of the different supposition in regard to the times to be used in the comparison of the negatives.

The short portion of the section, as shown on the Lick plate,

represents, without much doubt, a trail made by a detached mass of cometary matter during the exposure. It is of interest to know the probable dimensions of the mass that produced this trail. Evidently the beginning of the trail was made by the end of the mass which was nearest the head, and the other end of the trail was made by the farther end of the mass. The duration of the exposure was $5^h\ 30^m$. If we use the average hourly rate of recession obtained above, $12'.6$, the recession in five and one-half hours would be $69'$. The measured length of mass and trail was $104'$. Therefore the difference, $35'$, represents the length of the mass that made the trail. Measures of the width of the trail give $16'$ as the probable width of this mass.

Additional data with regard to the plates are contained in Tables IV and V. The comet's right ascensions and declinations were obtained by interpolation from Perrine's ephemeris (*L. O. Bulletin* No. 47), and from the early observations by Aitken and Maddrill, published in *Lick Observatory Bulletin* No. 49. For July 1 and 16, they were computed from the elements given in *Lick Observatory Bulletin* No. 47. The tables were computed by Bessel's formulæ as revised by Kreutz.[1] The designation of all the symbols used in the tables will be repeated here for purposes of ready reference.

t_1 and t_2 refer to the primary and secondary tails, respectively. p is the position angle, at the comet, of the pole of the comet's orbit. p' is the position angle of the Earth, at the pole of the comet's orbit, as seen from the comet. S is the angle at the comet between the pole of its orbital plane and the Earth. p_r is the position angle of the radius vector from the comet to the Sun. p_{t_1} and p_{t_2} are the position angles of the primary and secondary tails respectively. u_r is the angle between two planes through the comet, one of them containing the pole of the comet's orbit, and the north pole of the Earth; and the other containing the pole of its orbit and the radius vector from the Sun to the comet. u_{t_1} and u_{t_2} are similar angles, but in these cases the second plane contains the primary and secondary tails respec-

[1] *Publikationen der Sternwarte in Kiel*, "Untersuchungen über das Cometen-System 1843 I, 1880 I und 1882 II," Part I, p. 85.

TABLE IV.

Plate No.	Date, 1903	Pacific Standard Time			Comet's α	Comet's δ	Remarks	Observer
		Beginning	End	Mid-Exposure				
1	June 22	$13^h 50^m$	$15^h 35^m$	$14^h 42^m$	$21^h 51^m.6$	$-6° 59'$	t_1 very faint and short.	C.
2	June 23	11 45	15 30	13 37	21 50 . 8	− 6 5	t_1 narrow near head, then broadens.	C.
3	June 26	11 30	15 30	13 30	21 47 . 5	− 2 57	t_1 straight and very faint.	A.
4	June 29	12 20	13 13	12 46	21 42 . 8	+ 1 2	t_1 double, angle between branches 8°.	A.
5	June 30	11 33	15 33	13 33	21 40 . 7	+ 2 41	t_1 long, form indistinct, division in t_1.	C.
6	July 1	12 18	15 18	13 48	21 38 . 4	+ 4 27	t_1 sharp, narrow, single, and slightly curved.	A.
7	July 12	8 33	9 11	8 52	20 34 . 0	+39 32	t_1 4° long, somewhat indistinct.	A.
8	July 13	8 42	9 43	9 12	20 18 . 8	+44 36	t_1 straight and narrow.	A.
9	July 14	8 35	10 23	9 29	20 0 . 1	+49 42	t_1 long, narrow, straight, widening gradually.	A.
10	July 15	8 31	10 47	9 39	19 36 . 5	+54 39	t_1 long, straight, double (angle 7°.5).	A.
11	July 16	8 30	11 15	9 52	19 6 . 5	+59 11	t_1 straight and narrow, double near end.	A.
12	July 17	8 40	11 10	9 55	18 29 . 5	+63 10	t_1 long, straight, double (angle 8°).	C.
13	July 17	11 37	12 12	11 54	18 25 . 8	+63 25	t double and straight, also streamer from t_1.	C.
14	July 18	8 40	10 35	9 38	17 44 . 7	+66 5	See footnotes to Table IV.	C.
15	July 18	11 00	12 00	11 30	17 40 . 6	+66 17	Coma bright; also 2 streamers from t_1.	C.
16	July 19	8 52	10 7	9 30	16 52 . 4	+67 59	t_1 very bright near head; streamer on each side of t_1.	A.
17	July 19	10 35	12 35	11 35	16 47 . 6	+68 6	Bright coma; t_1 straight; streamer 2° long.	A.
18	July 20	8 58	12 58	10 58	15 55 . 7	+68 45	t_1 fan-shaped; narrow streamer 4° long.	A.
19	July 20	14 10	15 10	14 40	15 47 . 8	+68 46	Strong coma; t_1 faint and somewhat indistinct.	A.
20	July 23	9 00	14 30	11 45	13 47 . 0	+65 38	See text.	C.
21	July 24	9 00	14 30	11 45	13 19 . 3	+63 53	See text.	C.
22	July 25	9 00	15 00	12 00	12 57 . 4	+62 0	t_1 double, streamer each side of it.	C.
23	July 26	9 03	14 33	11 48	12 39 . 9	+60 10	See text; taken through clouds.	A.
24	July 27	9 22	11 17	10 20	12 26 . 6	+58 30	See footnotes to Table IV.	M.
25	July 28	10 18	13 18	11 48	12 14 . 0	+56 42	Streamers; t_1 faint in places.	A.
26	July 29	11 08	12 38	11 53	12 4 . 1	+55 6	t_1 has bend 2½° from head; streamers on each side.	A.
27	Aug. 11	8 39	9 00	8 49	11 0 . 2	+40 56	t_1 curved; streamers from head and t_1.	A.
28	Aug. 12	8 30	9 30	9 00	10 56 . 9	+40 4	Streamers from t_1 and from head; t_1 curved.	A.
29	Aug. 13	8 35	9 50	9 12	10 53 . 7	+39 13	Streamers from t_1 and from head.	C.
30	Aug. 14	8 29	9 41	9 05	10 50 . 6	+38 23	Streamers from t_1 and from head.	M.
31	Aug. 15	8 25	9 25	8 55	10 47 . 6	+37 32	Streamers from t_1 and from head t_1 somewhat curved.	A.
32	Aug. 18	8 19	8 53	8 36	10 38 . 4	+34 53	Impression faint; streamers on each side of head.	A.

Plate 14.—t_1 double for 1½° from head; then single and straight, becoming quite narrow at 3° from head, and then again widening out somewhat. Also very faint at 1½° from head.

Plate 24.—t_1 very narrow near head. Becomes double shortly after leaving the head, with an angle of 7° between the branches. Also a very faint streamer on the side opposite the short tail. The long tail has bend shortly after leaving the head to which is due the large residual $p_{t_1} - p_r$ for this plate.

TABLE V.

Plate No.	Date, 1903	P. S. T.	P	P'	S	p_r	p_{t_1}	$p_{t_1}-p_r$	u_r
1	June 22	14h 42m	260°.0	281°.4	56°.8	246°.0	248°.5	+2°.5	+109°.2
2	June 23	13 37	260.6	280.3	56.8	245.8	242.9	−2.9	+108.4
3	June 26	13 30	262.7	276.4	57.2	243.1	247.0	+3.9	+107.4
4	June 29	12 46	265.4	271.6	58.0	239.2	235.2	−4.0	+106.2
5	June 30	13 33	266.4	269.6	58.4	237.4	235.6	−1.8	+105.8
6	July 1	13 48	267.4	267.5	58.8	235.5	229.0	−6.5	+105.4
7	July 12	8 52	276.1	230.3	75.7	197.9	196.4	−1.5	+101.7
8	July 13	9 12	274.6	225.4	79.0	192.5	191.3	−1.2	+ 99.3
9	July 14	9 29	272.0	220.4	82.4	186.6	184.2	−2.4	+ 98.8
10	July 15	9 39	267.8	215.4	86.0	179.8	181.0	+1.2	+ 98.4
11	July 16	9 52	261.7	210.6	89.7	171.8	173.3	+1.5	+ 98.0
12	July 17	9 55	253.4	205.7	93.2	162.3	161.4	−0.9	+ 96.9
13	July 17	11 54	252.6	205.4	93.6	161.4	158.8	−2.6	+ 96.9
14	July 18	9 38	242.9	201.2	96.6	151.1	154.1	+3.0	+ 96.1
15	July 18	11 30	241.9	200.9	96.9	150.1	152.5	+2.4	+ 96.0
16	July 19	9 30	230.2	196.8	99.8	138.3	141.2	+2.9	+ 95.4
17	July 19	11 35	229.1	196.4	100.1	137.1	138.8	+1.7	+ 95.6
18	July 20	10 58	216.2	192.4	102.8	124.4	124.5	+0.1	+ 94.4
19	July 20	14 40	214.2	191.8	103.2	122.5	122.4	−0.1	+ 94.3
20	July 23	11 45	183.3	181.4	109.8	93.5	94.0	+0.5	+ 92.0
21	July 24	11 45	175.9	178.2	111.6	87.0	88.4	+1.4	+ 91.1
22	July 25	12 00	169.9	175.3	113.1	81.8	83.2	+1.4	+ 90.1
23	July 26	11 48	165.0	172.6	114.4	77.7	78.0	+0.3	+ 89.2
24	July 27	10 20	161.2	170.2	115.6	74.6	80.3	+5.7	+ 88.2
25	July 28	11 48	157.4	167.8	116.6	71.6	73.5	+1.9	+ 87.0
26	July 29	11 53	154.4	165.6	117.5	69.2	72.0	+2.8	+ 85.9
27	Aug. 11	8 49	132.5	146.0	122.5	46.6	46.9	+0.3	+ 63.6
28	Aug. 12	9 00	131.3	144.8	122.6	44.6	45.2	+0.6	+ 60.8
29	Aug. 13	9 12	130.1	143.5	122.7	42.5	43.6	+1.1	+ 58.0
30	Aug. 14	9 05	129.0	142.3	122.8	40.3	41.5	+1.2	+ 54.8
31	Aug. 15	8 55	127.8	141.1	122.8	38.1	39.7	+1.6	+ 51.6
32	Aug. 18	8 36	124.4	137.2	122.9	30.2	30.9	+0.7	+ 39.5

	Date, 1903	n	u_{t_1}	$u_{t_1}-u_r$	n_1	p_{t_2}	u_{t_2}	$u_{t_2}-u_r$	n_2
1	June 22	0°.559	107°.7	− 1°.4	0.56	222°.1	124°.4	+15°	0.64
2	June 23	0.560	110.2	+ 1.7	0.57	222.5	123.5	+15	0.64
3	June 26	0.565	105.1	− 2.3	0.56	225.3	118.9	+12	0.63
4	June 29	0.571	108.7	+ 2.6	0.59	216.8	122.6	+16	0.69
5	June 30	0.575	107.0	+ 1.2	0.54	215.6	122.3	+17	0.70
6	July 1	0.580	109.8	+ 4.5	0.61	213.4	123.0	+18	0.72
7	July 12	0.797	103.8	+ 2.2	0.82	190.7	122.1	+20	0.95
8	July 13	0.816	103.8	+ 4.4	0.86	187.9	118.5	+19	0.96
9	July 14	0.856	.....	......	....	.....	.....	....	....
10	July 15	0.891	.....	......	....	.....	.....	....	....
11	July 16	0.923	.....	......	....	.....	.....	....	....
12	July 17	0.947	.....	......	....	.....	.....	....	....
13	July 17	0.949	.....	......	....	.....	.....	....	....
14	July 18	0.966	.....	......	....	.....	.....	....	....
15	July 18	0.967	.....	......	....	.....	.....	....	....
16	July 19	0.981	.....	......	....	.....	.....	....	....
17	July 19	0.983	.....	......	....	.....	.....	....	....
18	July 20	0.991	94.8	+ 0.4	0.99	.....	.....	....	....
19	July 20	0.992	93.9	− 0.4	0.99	.....	.....	....	....
20	July 23	1.000	93.5	+ 1.4	1.00	99.1	108.1	+16	0.96
21	July 24	0.999	95.0	+ 3.9	0.99	93.9	109.1	+18	0.94
22	July 25	0.997	93.6	+ 3.5	0.99	91.2	112.2	+22	0.91
23	July 26	0.994	89.8	+ 0.6	0.99	89.1	113.8	+25	0.88
24	July 27	0.992	100.7	+12.5	0.95	86.9	113.4	+25	0.87
25	July 28	0.990	91.2	+ 4.1	0.98	83.7	110.9	+24	0.87
26	July 29	0.987	91.8	+ 5.9	0.97	83.0	111.7	+26	0.85
27	Aug. 11	0.994	64.2	+ 0.6	0.99	68.7	98.5	+35	0.82
28	Aug. 12	0.996	62.0	+ 1.2	0.99	67.3	96.9	+36	0.82
29	Aug. 13	0.998	60.0	+ 2.0	1.00	71.1	101.6	+44	0.78
30	Aug. 14	0.999	57.0	+ 2.2	1.00	67.9	97.9	+43	0.80
31	Aug. 15	1.000	54.5	+ 3.0	1.00	64.7	94.2	+43	0.82
32	Aug. 18	0.994	53.6	+14.1	1.00	64.2	93.8	+54	0.79

tively. The quantities n, n_1 and n_2 express the foreshortening of the radius vector and two tails respectively, due to their inclination to the line of sight. As u_{t_1} and u_{t_2} become indeterminate at the time of the Earth's passage through the plane of the comet's orbit, these quantities were omitted, in Table IV, from July 14 to July 20.

The difference $u_{t_2}-u_r$ is the angle which the secondary tail makes with the radius vector. It will be seen that this angle increases continually from the time of first observation up to the time of last observation on August 18. This increase may be due to the fact that the speed of the nucleus in the orbit was rapidly accelerated up to the date of perihelion passage, August 27, thereby causing this tail to lag behind more and more.

The negatives selected for reproduction illustrate in a general way the rapid changes which the comet's tail underwent. The first ten of these negatives were taken with the Pierson camera, and the remaining two with the Crocker telescope. The scale of the original negatives has been preserved in all of the accompanying cuts.[1]

Acknowledgments are due to Assistant Astronomer Perrine and to Fellow R. H. Curtiss, for valuable suggestions made during the progress of the work, and to Fellow J. D. Maddrill for checking most of the computations.

LICK OBSERVATORY,
January 12, 1904.

[1] Only three of these are reproduced in Plate XV.—EDS.

A PHENOMENON INVOLVED IN THE NEBULOSITY AROUND *NOVA PERSEI.*

By Otto Luyties.

The phenomenon described in this article is essentially a distortion phenomenon, affecting all sensible secondary radiations induced by new or varying primary emanations. The scope of the phenomenon, therefore, embraces a wide range of effect on terrestrial observations. As, however, its effect is most marked when the velocity of the primary emanations is greatest, it is particularly great in the case of astral emanations of high velocity. The discussion of this phase of its action is the purpose of this article.

While considering the nebulosity around *Nova Persei* two peculiarities attracted my attention: (1) the extreme rapidity of the expansion, and (2) its progressive retardation.

The expansion of the illumination was so rapid that on March 29, 1901, thirty-six days after the outburst of the *Nova*, Perrine observed the maximum radius of the inner and outer nebulous rings to be 89″ and 149″, and of an arc on the northeast side to be 321″.[1]

Assuming that the nebulous material moved, at least during the first part of its course, with a speed of 300,000 km a second, and applying this assumption to individual forms in turn, on the supposition that the initial motion was nearly radial, F. W. Very computes[2] from these radii $\pi = 0\overset{''}{.}014$, $\pi = 0\overset{''}{.}024$, $\pi = 0\overset{''}{.}052$, respectively. From this and another computation in the same article he concludes that the parallax $0\overset{''}{.}05$ may be definitely adopted as that of the *Nova*, and inferentially as that of the Milky Way in its vicinity. The objection to this computation is that it gives much smaller values for the dimensions of the Galaxy than appear probable from other considerations.

Now if, on the other hand, we assume the parallax of the

[1] Astrophysical Journal, **16**, 252, 1902.

[2] *American Journal of Science*, **16**, 127, 1903.

Nova to be less, say only 0".01, as given by Chase and Aitken, and compute the velocity of the radiations from this, making the other assumptions the same as before, we obtain 1,500,000 km per second as the velocity of the emanations. This result appears highly improbable, as we have no knowledge of any velocity greater than that of light.

Concerning the determination of parallax and of the velocity of the radiations from *Nova Persei*, Seeliger concludes[1] that "nothing is known as to V if the parallax π of the *Nova* is unknown." On the following page he remarks:

> For every assumed value of π we can find the corresponding surface which represents the illuminated stratum of nebula. The parallax of the *Nova* therefore remains undetermined, and it is not determinable from measurements of the photographs which are before us without the aid of further and quite arbitrary hypotheses.

The second marked peculiarity of the nebulosity around *Nova Persei* is the progressive retardation of its expansion. This has been urged by Very as an objection to some of the hypotheses assigning the nebular phenomenon to the action of radiation from the *Nova* on diffused quiescent matter already existing in surrounding spaces. The phenomenon described herein, however, explains this retardation.

The computation of parallax mentioned above is open to the fatal objection that it involves two tacit assumptions, of which one is erroneous. Of these two assumptions, the correct one is that the outermost rays that reach our eye determine the outer limits of the apparent illumination. The other assumption, which is incorrect, is that these outermost rays are caused by emanations of some kind originally at right angles to our line of sight.

It should be observed that coincident with the appearance of a new star we see first those luminous rays which come from the nearest points of the nebula. As time passes, more distant portions of the nebula become visible. If the near surface of the nebula is convex, the area of this visible portion will increase rapidly, yet at a progressively retarded rate. If a spherical nebula should spring into existence at its full ultimate size, its

[1] ASTROPHYSICAL JOURNAL, **16**, 189, November 1902.

apparent size would increase just as the portion of a sphere cut off by successive parallel planes increases. When, however, the nebula is produced by a central agency, the case is somewhat more complicated.

Let us, in all the following, assume the Earth to be at such a great distance from the *Nova* that all rays from the nebulosity to the observer may be treated as parallel, without essential error.

Let us assume emanations radial and equal in all directions to cause the space surrounding a body to become luminous. Then the visible illuminated space will be part of a prolate ellipsoid of which the body is a focus. The distances from the focus to the apsides will be the product of the time and the velocities of the primary and secondary radiations divided by their sum and difference, respectively. From these functions all other dimensions of the ellipsoid can readily be computed. The apparent radius of the illumination will be equal to the conjugate radius of this ellipsoid. The distortion of the image of the nebulosity will be equal to the ratio of this radius to the semi-latus-rectum. This is true unless the maximum radius of the illumination is less than the transverse radius of the ellipse, in which case this radius (*OA* in Fig. 1) determines the limits of the illumination. (If, in a special case, the velocities are equal, the locus of farthest visible points in the nebulosity at any time will be, as suggested by Kapteyn, part of the surface of the ellipsoid whose foci are the radiating body and the Earth.) Then the complete locus of all sensible secondary points of radiation will be the portion of this ellipsoid which is included within a spiraloid of revolution whose radius is the greatest distance at which the primary emanations at successive periods can cause the secondary.

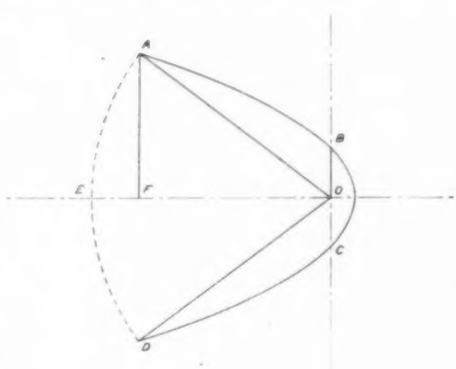


FIG. 1.

If, as a special case, we assume the primary emanations to travel with the speed of light, and to be of a uniformly sustained intensity in all directions, the form of the nebula will be a paraboloid with spherical base, as shown in section in Fig. 1. *OA* is equal to the maximum radius of the illumination (*i. e.*, the point *A* is as far as the illuminating action of the *Nova* can reach); *OE* and *OD* are equal to *OA*. The distance *OB* is the distance traveled by light during the visibility of the *Nova*, while the distance *FA* is the radius of the apparent illumination. *FA* increases at a very rapid rate, which is, however, progressively retarded from infinity to zero, and ultimately coincides with *OB*. I shall call (1) the ratio of this maximum radius (or the transverse radius of the ellipse, whichever is the smaller) to the distance traversed by the primary emanations in the time considered (*OA* to *OB* in the figure) the "extension;" (2) the ratio of the apparent radius to the distance covered by the primary emanations in the time considered (*FA* to *OB* in the figure) the "actual distortion;" and (3) the ratio of the apparent illumination to the distance covered by light in the time considered (*FA* to *EF* in the figure) the "relative distortion." I submit a table of these ratios for primary radiations with velocities of $1\frac{1}{2}\,V$, V, $\frac{3}{4}\,V$, $\frac{1}{2}\,V$, and $\frac{1}{4}\,V$, all for a maximum radius of ten units of time, where V is the velocity of the secondary radiations.

TABLE I.

Approximate Distortion of the Image.

"Extension"		Actual Distortion, *FA* to *OB*					Relative Distortion, *FA* to *EF*				
Time	$\frac{OA}{OB}$	$1\frac{1}{2}V$	V	$\frac{3}{4}V$	$\frac{1}{2}V$	$\frac{1}{4}V$	$1\frac{1}{2}V$	V	$\frac{3}{4}V$	$\frac{1}{2}V$	$\frac{1}{4}V$
1	10.00	5.49	4.36	1.51	1.15	1.03	8.24	4.36	1.13	0.58	0.26
2	5.00	2.95	3.00	1.51	1.15	1.03	4.42	3.00	1.13	0.58	0.26
3	3.33	2.09	2.38	1.51	1.15	1.03	3.13	2.38	1.13	0.58	0.26
4	2.50	1.61	2.00	1.51	1.15	1.03	2.42	2.00	1.13	0.58	0.26
5	2.00	1.32	1.73	1.51	1.15	1.03	1.98	1.73	1.13	0.58	0.26
6	1.67	1.11	1.53	1.50	1.15	1.03	1.67	1.53	1.12	0.58	0.26
7	1.43	0.95	1.36	1.47	1.15	1.03	1.43	1.36	1.09	0.58	0.26
8	1.25	0.83	1.22	1.39	1.15	1.03	1.24	1.22	1.04	0.58	0.26
9	1.11	0.72	1.10	1.32	1.15	1.03	1.08	1.10	0.99	0.58	0.26
10	1.00	0.63	1.00	1.25	1.15	1.03	0.94	1.00	0.94	0.58	0.26

Individual points in Fig. 1 might conceivably decrease in brightness approximately as the square of their distance from O. It should be observed, however, that the *Novæ* generally fade very rapidly, so that in an actual case only the paraboloidal shell $ABCD$ will be very bright, and OE will be much shorter than OA. The radius OA is dependent on the radiating power of the *Nova;* if, therefore, the *Nova* does not radiate uniformly in all directions, OA will vary as it approaches OB. As OA is probably dependent on quiescent matter in the space about the *Nova*, it will vary with the distribution and susceptibility of this matter.

Let us consider a special case, with the following assumptions: (1) the nebulous matter to be uniform in distribution and susceptibility; (2) the primary emanations to be equal in all directions; (3) the primary emanations to travel with the same velocity as the secondary; (4) the maximum radius of the illumination to be ten units; (5) the primary emanations to decrease in intensity and radius of action as given in Table II. Then Figs. 2, 3, and 4 will be sections of the visible nebulosity at the time indicated for each.

TABLE II.

Radii of Illumination Assumed in Figs. 2, 3, 4.

First Assumption			Second Assumption		
Time	Mag.	Rad. of Illum.	Time	Mag.	Rad. of Illum.
0	0	39.8	0	0	39.8
1/30	1	25.1	1	1	25.1
4/30	2	15.8	2	2	15.8
10/30	3	10.0	3	3	10.0
1	4	6.31	4	4	6.31
2	5	3.98	5	5	3.98
4	6	2.51	6	6	2.51
7	7	1.58	7	7	1.58
10	8	1.00	8	8	1.00
			9	9	0.60
			10	10	0.40

In order to consider a particular case, let us refer to the velocity of light as V, the parallax of the *Nova* as π, and the velocity of the unknown emanations from the *Nova* as V_1. Let us, for example, consider the photograph of *Nova Persei* taken

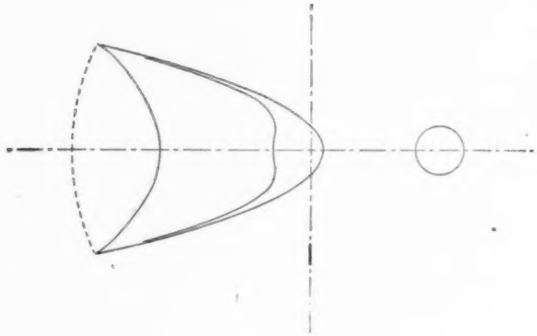


FIG. 2.

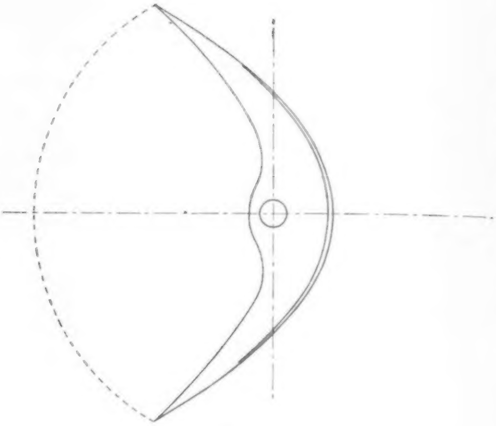


FIG. 3.

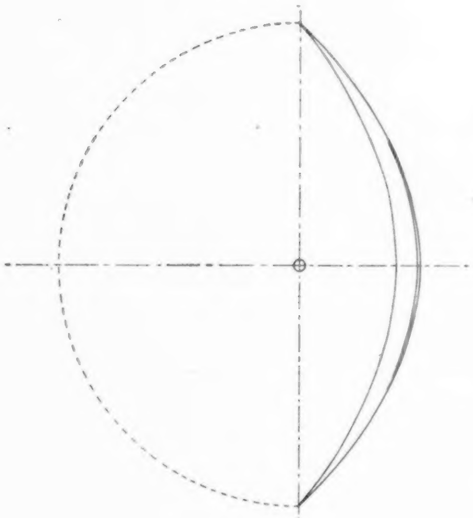


FIG. 4.

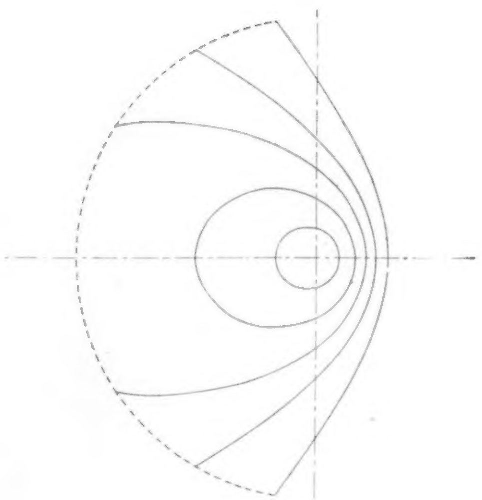


FIG. 5.

FIG. 2 shows in section the locus of visible points in the assumed nebula, after one unit of time. The small sketch to the right shows the relative size of a sphere expanding with the velocity of light during the same period.

FIG. 3 shows same after five units.

FIG. 4 shows same after ten units.

FIG. 5 shows the loci of all visible emanations traveling with velocities 1½ *V*, *V*, ¾ *V*, ½ *V*, and ¼ *V*. The parabola is the same as that given in Fig. 3.

by Perrine on March 29, 1901, showing nebulous material at a distance of 321″, 149″, and 89″ from the *Nova*. Let us suppose, for argument's sake, that emanations of various speeds are possible, with velocities of $1\frac{1}{2}V$, V, $\frac{1}{2}V$, and $\frac{1}{4}V$. Then, by the direct method, we obtain as follows from the outermost arc:

Assumed V_1	Direct π	Distortion	Corrected π
$V_1=1\frac{1}{2}V$	0″035	8.24*	0″004
$V_1=V$	0.052	4.36*	0.012
$V_1=\frac{1}{2}V$	0.104	1.15	0.090
$V_1=\frac{1}{4}V$	0.204	1.03	0.198

The distortions marked * for $V_1=1\frac{1}{2}V$ and $V_1=V$ are for an "extension" of 10, which is merely an estimate.

Now, as it is not probable, from other considerations, that the parallax of the *Nova* is as large as 0″09 or as small as 0″004, we can reasonably conclude that the velocity was V, nearly or exactly.

As a matter of fact, assumptions of velocities differing from that of light for the nebulosity about *Nova Persei* can be proved improbable from other considerations of this distortion phenomenon. Very has suggested[1] that

> Perrine's observation of March 29, 1901, indicates the existence, at that date, of two nebulous rings, with radii in the ratio of 1 : 2 and an arc on the N. E. side, which perhaps is the sole record of a third and wider ring. The three radii having approximately the ratio of 1 : 2 : 4 may correspond to ions having masses in the ratio of 4 : 2 : 1, and, if so, bear witness to the existence of at least three sorts of ions out of which, in varying proportions, we may conceive the atoms to be made.

If we observe, however, that the distortion corrections for this photograph are very different for V, $\frac{1}{2}V$, and $\frac{1}{4}V$, the apparent agreement for the outer arc is destroyed and the ratio of the inner to the outer ring is rendered less exact.

It will be evident from Table I that when the primary emanations have a smaller velocity than the secondary, the distortion is a constant. As, therefore, a nebula expanding with a velocity less than that of light would increase at a slow and uniform rate,

[1] *Am. Jour. Sci.*, **16**, 56.

we can safely conclude that the velocity of the emanations from *Nova Persei* was *not less* than that of light.

Now if, on the other hand, the nebula, as variously suggested, had actually expanded with a velocity greatly in excess of that of light, then the nebulosity would have been visible *before the Nova*. Fig. 6 shows in section the loci, at the moment when the *Nova* itself becomes visible, of possible visible points in three nebulæ, expanding with velocities equal to 10 *V*, 2 *V*, and 1½ *V*.

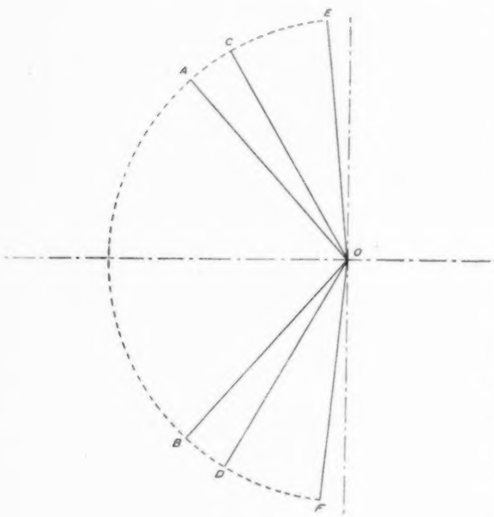


FIG. 6.

From the above discussion it appears evident that the emanations from *Nova Persei* must have traveled with approximately or exactly the velocity of light. It should be observed that this conclusion is entirely independent of all hypotheses as to the nature of these emanations.

I hope that someone will now make a careful computation of the parallax of the *Nova* from its nebulosity with due allowance for the phenomenon described above. The following additional suggestions may be found useful:

1. The actual rate of expansion will be to the apparent rate as the versed sine is to the sine of the angle made by the *Nova*, the Earth, and that point of the visible nebulosity which appears to be most distant from the *Nova*. In other words, the "distortion" will be the "extension" times the sine of its angle.

2. If the nebulosity is due to radiations from the *Nova* upon quiescent matter, the apparent radius of the illumination will vary with the distribution and susceptibility of this matter in spaces through which the locus passes.

3. The radius of illumination will also vary, if the *Nova* does not radiate equally in all directions, or if its radiations are not transmitted uniformly.

4. The apparent brightness and apparent radius of the nebulosity may be unduly increased at first, and decreased at the last owing to the faintness of the outer limits of the illumination. This is because the effect on the photographic plate depends on the thickness of the luminous layer as well as on its degree of brilliancy.

5. On the other hand, if the nebulosity be due to reflection from diffused quiescent matter, the radius of the apparent illumination may be much reduced at first, owing to poor reflection when the rays are received and reflected at such an obtuse angle.

6. The direct method, which involves the assumption that the sine of the "extension" is unity, may give correct results when the *Nova* has ceased to expand, because the actual and apparent radii of the illumination will coincide. The method will be very inexact in application, however, because it will be almost impossible to determine by direct observation the exact period when the nebulosity ceases to expand, owing partly to the irregularity and continuous backward motion of the image, and more particularly to the fact that the rate of expansion is so minute at the end.

7. The very fact that the nebula does not expand or contract appreciably for some time when near its maximum should enable an observer to find the maximum radius of the illumination from a great number of observations, and therefore with satisfactory accuracy.

8. The date of first appearance of the nebulosity should be determined with the greatest possible precision. I believe that it has generally been assumed that the nebulosity around *Nova Persei* began to expand on the night of February 21 to 22, 1901, when the *Nova* was first observed by Dr. Anderson, of Edinburgh. It is not at all certain that this assumption is correct, as it is not proved that the emanations causing the surrounding space to become luminous began at the time of the greatest magnitude of the *Nova*. Accuracy at this point is important, because the rate of apparent expansion is so very rapid at first.

9. It will be observed that the assumed values for the

intensity of the primary emanations given in the first part of Table II agree roughly with the observed visual magnitude of *Nova Persei* at monthly intervals. On reference to Figs. 2, 3, and 4 we see that the area of the visible nebulosity under this assumption is very small. The second assumption, which is merely a random example, gives an outline agreeing somewhat better with the observed nebulosity. It is therefore apparent that an objection to the theory of reflection of ordinary light lies in the observed persistence of certain definite forms in the nebulosity. Of course, a very thin luminous paraboloidal cup, moving with from half to full velocity of light, should show rapid changes in the visible formations.

This distortion phenomenon will affect the image of a nebulosity regardless of the actual nature of the primary emanations. It will affect the image even when the emanations are not radial or not of uniform velocity.

The purpose of this article is merely to describe some of the characteristics of this phenomenon. I hope that it may contribute toward a solution of the problems of *Nova Persei*, and ultimately find a wider application.

BALTIMORE, MD.,
January 1904.

THE ABSORPTION OF RADIATION BY THE SOLAR ATMOSPHERE AND THE INTRINSIC RADIATION OF THAT ATMOSPHERE.

By Frank W. Very.

In 1877 Dr. H. C. Vogel showed by his spectrophotometric measures at different points in the solar image that the absorption exercised by the solar atmosphere on light from the photosphere decreases somewhat regularly from the violet toward the red end of the spectrum; and it is now known that the same law continues far out into the infra-red. While there are some exceptionally strong absorption lines in the violet and ultraviolet part of the solar spectrum, it is evident at once that their number is insufficient to account for the large increase of absorption in these regions, nor is there such a marked concentration of the Fraunhofer lines toward the shorter wave-lengths as will explain the systematic progression in the absorption coefficients of the solar atmosphere. Moreover, a critical examination of the appearance of the Fraunhofer lines from different parts of the solar disk discloses the remarkable fact that they do not vary appreciably at any point of the unspotted surface, and can have nothing to do with the progressively increasing selective absorption deduced from comparisons of radiation at various radial distances in the solar image. This depletion by the solar atmosphere, which increases as the wave-length diminishes, is therefore properly attributed to selective scattering, or diffraction, by fine particles, and not to any true absorption by gaseous constituents of the media traversed by the rays.

Miss Clerke, in her *History of Astronomy in the Nineteenth Century*,[1] refers to the comparison of the intensity of the Fraunhofer lines at the Sun's limb and from the entire disk, as inferred by Professor Forbes, of Edinburgh, from observations of the annular eclipse of May 15, 1836, as follows:

[1] Fourth edition, p. 134.

If the problematical dark lines were really occasioned by the stoppage of certain rays through the action of a vaporous envelope surrounding the Sun, they ought, it seemed, to be strongest in light proceeding from his edges, which, cutting that envelope obliquely, passed through a much greater depth of it. But the circle of light left by the interposing Moon, and of course derived entirely from the rim of the solar disk, yielded to Forbes' examination precisely the same spectrum as light coming from its central parts. This circumstance helped to baffle inquirers, already sufficiently perplexed. It still remains an anomaly of which no satisfactory explanation has been offered.[1]

As it seems to me that a sufficient explanation of the supposed anomaly is not far to seek, I desire to point out that in my research on "Atmospheric Radiation"[2] it is shown that increasing the depth of a radiating gas gives progressively diminishing increments of radiation; that, for example, the maximum efficient radiant depth for the flame of illuminating gas from a Bunsen burner, or from a series of such burners, cannot be much over 20 cm; that the radiating power of carbon dioxide is not appreciably increased after the depth of the radiating layer of gas surpasses 90 cm; and that, in general, the depth of the efficient radiating layer of a gas amounts to only a few meters in the case of the feeblest radiators. Consequently, the radiation of a gas is limited by the self-absorption which the gas exercises on its own radiation, proceeding from inner depths of the gaseous mass; and similarly, the line-absorption produced by a gas does not increase indefinitely with the depth, but after a certain mass of the gas has been traversed, all the lines capable of absorption by this gas are stricken out from the spectrum, and the remaining rays pass freely.

Radiation from glowing chromospheric masses of incandescent hydrogen, thousands of kilometers in depth, is still a comparatively superficial affair. Some increase of the total emission must occur, however, from the integration of radiation proceeding from successive layers of chromospheric substance appertaining to different levels, because the deeper layers are usually at higher temperature and pressure, and under these conditions the vibrations of the incandescent particles are damped and distributed through a wider range of frequency. Even if it should

[1] *Phil. Trans.*, **126**, 453. [2] *Bulletin G, U. S. Weather Bureau*, p. 62.

be proved that the wide, hazy fringes attending many of the lines, especially those which are prominent in the chromospheric spectrum, are due to anomalous dispersion, the darkest, and distinctly, or suddenly, accentuated central cores must be attributed to absorption. The monochromatic spectral images from the deeper layers are broadened, and the rays corresponding to the outer margins, which the lines then assume, pass unimpeded through the more elevated layers of rarer gas whose particles vibrate within narrower limits. But the rays which represent the cores of the spectral lines, and which proceed from the deep layers, are entirely absorbed by the outer layers with whose periods they are completely in tune. Since the outer strata of the atmosphere are at a lower temperature, their emission of core rays is feebler, and cannot compensate those rays of the deep-layer emission which are absorbed. The double-shouldered lines of the flash spectrum have been explained by Jewell on this principle, but are equally well accounted for on the supposition that the wings are due to anomalous dispersion, as has been shown by Julius.[1] The broadening of the spectral lines from absorption by chromospheric layers having a wide range of pressure does not infringe the general principle that each element, or corresponding pair of elements, of a spectral line is due to a layer of small depth. Because of this small depth of material concerned in the production of the Fraunhofer lines, it makes almost no difference whether the local origin of the rays is near the center or at the margin of the solar disk. As far as the Fraunhofer lines are in question (for a reason which will be mentioned presently), it appears certain that at all points of the Sun's photospheric surface, and for every sort of material, the depth of overlying atmosphere is always more than enough to produce the full amount of absorption which can result with the given pressures and temperatures. If the relative amount of a particular ingredient changes, the variation in the proportional part of the pressure, due to this substance, will involve a change in the breadth and intensity of its spectral lines. To such changes, the peculiarities observed in the spectra of Sun-spots

[1] ASTROPHYSICAL JOURNAL, 15, 28–37, 1902.

may be partly attributed; and in like manner an alteration in the depth and total pressure of the layers above the photosphere is sufficient to account for many of the variations noted in the different classes of stellar spectra without the need of supposing extensive diversities of composition.

The failure of the Fraunhofer lines to become intensified at the Sun's limb is to be attributed chiefly to the corrugation of the photospheric surface, and to the fact that the efficient absorbing layer is of a depth not great in relation to the vertical dimensions of these irregularities. That part of the solar atmosphere which produces the line-absorption is a relatively shallow layer whose section in the line of sight is, on the average, approximately the same for all parts of the solar disk. The greater part of the central radiation comes from the depressed surfaces, and has traversed, before arriving at the level of the summits of the photospheric elevations, enough absorbent material to experience about the same line-absorption as the marginal rays which proceed almost wholly from the tops of the photospheric clouds. The selective depletion of radiation by diffraction, on the other hand, increases very rapidly near the limb, proving that this part of the loss comes from the action of a deeper atmosphere, compared to which the dimensions of the irregularities are of less importance, although they are by no means without influence.

It seems to me that the invariability of the Fraunhofer lines is sufficiently explained on these principles. The general absorption which produces the darkening of the Sun's limb has nothing to do with the Fraunhofer lines, but is to be explained in the same way as that part of the depletion of solar rays in passing through the terrestrial atmosphere which comes from the scattering of sky light.

In Professor Schuster's article "The Solar Atmosphere"[1] a considerable portion of solar radiation is assumed to come from an absorbent and radiating layer, distinct from and immediately above the photosphere, and the apparent change of absorption at different distances from the Sun's limb is explained as due to the varying relative preponderance of the two sources—photosphere

[1] ASTROPHYSICAL JOURNAL, **16**, 320, 1902.

and atmosphere—in producing the radiation. The symbol I is used for photospheric radiation, and F for "the radiation of a perfectly black body which is at the temperature of the shell' constituting the absorbing atmospheric layer. This supposition implies that the absorbent matter consists of perfectly black particles suspended in a medium. The medium, as a whole, cannot radiate like a perfectly black body, for in this case it would also be perfectly opaque to the photospheric radiations presented for transmission. On p. 326[1] it is said that "there is no reason to look for a different region in the Sun's surroundings for the cause of the observed diminution of radiation, than that which gives the Fraunhofer lines;" and it is inferred that "the layer which gives the line absorption absorbs also to some extent all wave-lengths extending from infra-red to violet."

It will be seen that great importance is attached to the black absorbent particles as radiators, and that no use is made, in this theory, of particles which scatter the photospheric rays selectively. This view is partly supported by those eclipse spectrograms which indicate the presence of incandescent particles giving a continuous spectrum, and no sensible spectrum crossed by Fraunhofer lines, at least in the inner region of the corona, although Professor Schuster does not avail himself of this evidence, and indeed excludes it by limiting his radiant shell to the reversing layer which gives the Fraunhofer lines. In spite of the spectrograms mentioned (which are perhaps not conclusive in their evidence, because a small addition of continuous spectrum makes the Fraunhofer lines difficult to detect), it has seemed to me that there must be depletion of the photospheric radiation by selective scattering from fine particles taking place somewhere in the Sun, because the solar atmosphere limits the spectrum at the ultra-violet end nearly as the Earth's atmosphere does, namely, at a wave-length of about $0.3\,\mu$. The crowding of the solar Fraunhofer lines at the shorter wave-lengths also contributes something to the effect, but here I shall confine myself to depletions which are not in the nature of line-absorptions.

Professor Schuster's theory appears to demand that the

[1] *Loc. cit.*

coefficient of transmission (called Z in his notation) shall be about the same for all wave-lengths and his computation assigns nearly equal values for Z in the red and the violet. Anyone who has compared the strongly contrasted colors — blue at the center and reddish-brown at the limb of the Sun — will recognize that, if this explanation is to be accepted, the radiation at the limb must come almost entirely from the red-hot particles of the envelope, while the blue-hot photosphere is mainly in evidence at the center; and the absorption by the outer shell must be the general or non-selective one produced by opaque particles too coarse to give much of any selective reflection.

It is a fact that, at the photospheric level, some form of matter exists which does radiate indiscriminately through a wide range of wave-length, and whose particles are presumably coarse enough to act non-selectively in other respects. But immediately above the photosphere this quality disappears, to all appearance absolutely, suggesting that the conditions here do not permit the existence of the material out of which photospheres are made, unless in some excessively attenuated form, while the purely bright-line spectrum of the reversing layer further suggests that the medium at the higher altitude resembles the blue flame of a Bunsen burner, in that its particles, being in a state of atomic, or perhaps ionic, resolution, are too small to scatter the rays. If we form an image of the Sun by a powerful condensing lens on a Bunsen flame, it can scarcely be detected; but turn off the air at the base of the burner, restoring the illuminating quality to the flame, and at once you will see a dazzling bluish image of the Sun projected on the flame. The light has here been selectively scattered by fine particles, but by particles much coarser than any which exist in the blue flame. It would seem that if the solar atmosphere contains particles capable of producing such scattering effects, they must be in the photosphere itself, or in some exceedingly thin layer immediately in contact with its surface, possibly an attenuation of its substance, and not simply in a layer as thick even as the chromosphere. Higher up, coarse particles exist only as rare strangers. Still higher up, coarse particles cannot float quiescently, although such particles

may be temporarily present while in swift transit, either because they are electrified and repelled, as is suggested by the trumpet forms of coronal extensions, and by the general agreement of the filaments with such forms as streams of electrified particles assume under magnetic control, or because the particles have been mechanically expelled from the Sun and are passing out along orbits, perhaps to merge in the nebulous zodiacal light. In any case, these moving particles must be sparsely distributed, and a great depth of such a dust-laden medium, or of such dust-sown space, will be needed to produce an appreciable effect by intercepting rays of light.

Suppose, however, that we grant the existence of a thin layer having the properties of Schuster's absorbing medium. Will it be distinguishable from the photosphere, and will it fulfil the requisites of his theory?

As no substance is absolutely black, or opaque, through more than a limited range of the spectrum, there are spectral regions where particles of such opaque substances cease to absorb or radiate, and where, consequently, the photospheric radiation may be able to penetrate the hypothetical atmosphere readily. Professor Schuster's analysis shows, however, that, owing to the compensation which results from his theory, parts of the spectrum where the absorption is very great cannot be discriminated from those where the absorption is very small. This follows from the equation:

$$A = (I - F)\, Z^{\sigma} + F,$$

where the mean value of F (the dispensable energy of the envelope which can appear as intrinsic radiation) increases as the transmissive power of the solar atmosphere (Z) diminishes. Hence "constancy of radiation for different distances from the Sun's limb may be due either to smallness of the coefficient of absorption, in which case the radiation is everywhere equal to I, or to its greatness, in which case the radiation is everywhere equal to F, or finally to the near equality of I and F." The argument, like some others appertaining to the subject, is of the inconclusive sort.

Let us suppose, however, that the absorbent medium is not so

dense but that a considerable amount of photospheric radiation can penetrate it, and that it supplies a radiation of its own at a lower temperature. This is the main point of Schuster's theory, which requires the combination of spectra whose energy-curves have widely separated maxima. The photosphere has a columnar structure, best seen when dissected in the penumbra of Sun-spots. This structure indicates strong ascending and descending currents, such as we should expect to find produced by convection when the masses of matter, cooled at the surface of the radiating photosphere, seek their level. In the Earth's atmosphere a few degrees, difference of temperature, not often more than 30°, is sufficient to induce the convectional overturnings of the most severe local storms or tornadoes. Bigelow[1] calculates that under solar conditions a few hundred degrees' fall of temperature may be expected in passing through the photosphere. The argument assumes that the photosphere is a condensation-cloud, which seems permissible. If the fall of temperature of a few hundred degrees is sufficient to account for violent movements within the photosphere, however, it is still not great enough to give, at the high temperature of the Sun, more than a very small change in the wave-length of the maximum ordinate in the spectral energy-curve, and not enough for Schuster's explanation of the variation in the apparent solar absorption by which the marginal regions seem more transmissive. Unless it can be shown that there is a probable fall of temperature of some thousands of degrees within this narrow region, this objection greatly diminishes the efficiency of the process proposed by Schuster as the sole one needed. I think we must conclude that no mere skin-layer of attenuated photospheric material is competent to absorb and radiate in the manner required.

My reasons for assuming that the intrinsic radiation of the envelope is relatively small have been founded on Abbot's observation that the corona is "giving light in a manner not associated with a high temperature, or at least with the preponderance of infra-red rays," coupled with Perrine's statement that coronal light resembles sky light, from which we may conclude, I think, that

[1] *Eclipse Meteorology*, etc.

there is a selective scattering of the shorter waves of ether by the solar coronal envelope whose particles are too small to affect the longer infra-red rays. This, taken in conjunction with the apparent cessation of the solar spectrum at about $\lambda = 0.3\mu$, after allowing for the great absorption by the Earth's atmosphere in this region, seems to indicate that the depletion of photospheric radiation by the solar atmosphere, aside from the line-absorption, resembles the action of the Earth's atmosphere in being largely due to selective scattering principally of short waves by fine particles; and this characteristic of the outer and more transparent regions of the solar atmosphere presumably continues and is reinforced in the denser layers.

A further reason for assuming that the general intrinsic radiation from a very thin absorbent envelope is a relatively small quantity is that the brightness of the general spectrum, just outside the Sun's limb, is only a small fraction of the brightness of the photospheric spectrum, in spite of a large admixture of bright photospheric light diffused into the neighboring chromospheric region by our hazy atmosphere. With a slit 1 mm wide, held tangent to the Sun's limb, and with a large dispersion, the general chromospheric spectrum is about as bright as the photospheric spectrum with a slit 0.01 mm wide. The dilution of the spectrum by diffuse sky light possibly constitutes nine-tenths of the light observed. Hence the general chromospheric spectrum is perhaps one-thousandth as bright as the spectrum of the photosphere; that is $F = 0.001 \times I$, instead of $F = I$, or at the least, and for the visible spectrum, $F = \frac{1}{3} \times I$, as Professor Schuster is obliged to assume.

In the flash spectrum of the reversing layer, selective radiation, reinforced by anomalous dispersion, immensely preponderates over general radiation; yet the total of selective and general radiation falls far short of that from the photosphere. Consequently, while the process investigated by Professor Schuster no doubt exists to some extent, and while its effect in producing an apparently greater transmission of the marginal rays is in the same direction as that of other causes enumerated in my earlier paper,[1] and must be added to them, it seems to constitute only a

[1] ASTROPHYSICAL JOURNAL, **16**, 73–91, 1902.

minor part of the complete series of causes, and the seat of its action does not appear to reside exclusively in a thin shell, practically coincident with the reversing layer. The efficient radiating layer is probably deeper than the inner corona, but is nevertheless of comparatively limited depth. Two to eight minutes of arc from the Sun's limb are the limits assigned by the spectrograms of the Lick Observatory eclipse expeditions. Selective scattering, on the other hand, is not only not confined to such a thin layer, but acts from fine particles suspended at levels where the atmosphere is too rare to support the coarser particles which radiate, but are not able to act selectively on the passing rays, as well as from fine particles moving rapidly through free space in the farthest reaches of the outer corona.

In view of the arguments in the present paper, it now seems to me probable that the regions very close to the photosphere, and within its interstices, are the ones where something like a thin mist of photospheric material still lingers, and where the principal part of the selective scattering takes place. A wider region, approximately the inner corona, whose spectrum is largely continuous, constitutes the field throughout which the combination of absorption and intrinsic radiation, described by Schuster, acts, the result of the process being much less important than the effect of selective scattering. Finally, the outer corona continues the depletion by selective scattering, but to an extent which is relatively insignificant, and all of the regions have their special discontinuous absorptions and radiations, producing the spectrum of fine lines.

The effect of a scattering medium would seem to be the same as that of an absorbing medium in preventing the escape of radiation from a heated surface, provided the surface radiates the short waves which are scattered by the particles of a certain degree of fineness, peculiar to the scattering medium; but if only long waves are emitted, these are not much scattered by the same medium, and there is no cumulative action by which the retention of radiation will cause the temperature of the surface to mount until short waves are emitted on which the scattering medium can take effect.

On the other hand, an absorbing medium *may* cause a cumulative retention of heat; hence there is a difference between the actions of the two classes of media.

From the depths of the Sun, radiations composed mainly of very short waves tend to proceed, and a very extensive scattering atmosphere acts almost like a reflector, sending nearly all the rays back again. In this case the medium will not be much heated by the process. Only a small fraction of the incident rays will be absorbed by the fine particles; the greater part is by assumption diffracted. Still, as the course of the rays through such an extensive scattering medium is a zigzag one, the scattering being repeated over and over again, some cumulative action and some absorption of energy by the medium must result. Consequently, it is not possible to separate completely the two causes—absorption and scattering.

There is a difference between the action of an extensive and a thin scattering medium. In the extensive medium, or in one densely loaded with the scattering particles, radiation is bandied about so many times before it can escape that a considerable fraction of the energy is absorbed and retained in the medium, thereby raising its temperature, even though the absorbing power of the particles may be small. In the thin medium scarcely any absorption takes place, and the temperature is hardly raised at all, because there is no chance for a long series of recurrent scatterings upon the same luminous energy.

Obstruction to the passage of rays offered by scattering particles will not, in this view, bear any constant proportion to retention of energy by the medium itself. It seems possible to imagine a medium in which there is no absorption whatever, and yet so densely laden with diffracting particles that light might be a long time in getting out of it, that is, in getting reflected back again on its source; for, as Schuster supposes, such a medium would be opaque, and yet the medium would not be warmed by the rays.

The nearly constant radiation of Sun-spots as they approach the limb, for which Professor Schuster gives an explanation

according to his theory, is quite as simply explained on the theory of selective depletion of the shorter waves by the Sun's atmosphere. The spot is cooler and gives a greater proportion of radiations of long wave-length, which are more transmissible than those of the general surface.

WESTWOOD, MASS.,
December 1903.

EIGHT STARS WHOSE RADIAL VELOCITIES VARY.

By EDWIN B. FROST and WALTER S. ADAMS.

OUR current observations of stars of the *Orion* type indicate that the following eight stars vary in their velocity in the line of sight. The variation of three of these was suspected[1] from the examination of the plates taken last season with a dispersion of three prisms; but the diffuse character of the lines rendered the measurements with high dispersion very difficult, and with a dispersion of only one prism the determinations are by no means easy or precise.

These measurements, and all others that we have published for stars of the *Orion* type, are to be regarded as merely provisional, since the wave-lengths of certain of the stellar lines (particularly those of silicon) have as yet been only approximately determined in the laboratory, and certain other lines (especially those of hydrogen at λ 4542 and λ 4686) have not been seen in the laboratory. We expect to be able to publish later fairly accurate wave-lengths of these hydrogen lines, as determined from the stars, since we always measure them when sufficiently sharp to be set upon in a stellar spectrum. When we are able to utilize these measures, which we have not yet done, the accuracy of the radial velocities will be appreciably increased.

We defer until a later communication the measures of the velocities of θ^1 and θ^2 *Orionis*, of which we are obtaining as many plates as possible, as the stars promise to be of especial interest. We have been able to secure measurable plates of the other brighter stars of the trapezium besides θ^1, which at the same time yield values of the radial velocity of the *Orion* nebula.

The magnitudes given are from the Revised *Harvard Photometry*.

[1] ASTROPHYSICAL JOURNAL, 17, 246, 1903.

g Persei ($\alpha = 1^h\ 56^m$; $\delta = +54°\ 0'$; Mag. = 5.0).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 176	1903, Nov. 7	$15^h\ 41^m$	F.	−21	−27	3	3	−24
191	Nov. 17	12 56	A.	−19	−21	. 3	3	−20
200	Dec. 1	13 43	F. A.	−13	−10	3	4	−12
260	1904, Jan. 23	14 45	A.	+ 8	+12	3	5	+10

The hydrogen lines γ and β and *Mg* λ 4481 are quite sharp in the spectrum of this star, and are well adapted for measurement. The helium lines are not conspicuous. The hydrogen lines at λ 4542 and λ 4686 are present, but faint.

ε Persei ($\alpha = 3^h\ 51^m$; $\delta = +39°\ 43'$; Mag. = 3.0).

Plate	Date	G. M. T.	Taken by	Velocity F.	Velocity A.	No. of Lines F.	No. of Lines A.	Velocity Mean
				km	km			km
IB 180	1903, Nov. 7	$19^h\ 38^m$	F.	− 3	− 5	4	4	− 4
192	Nov. 17	13 36	A.	−26	−30	3	5	−28
202	Dec. 1	15 20	F. A.	−29	−19	4	3	−24
228	Dec. 26	19 3	F.	+15	− 3	3	4	....
261	1904, Jan. 23	15 23	A.	−18	− 2	3	5	....

In this spectrum the hydrogen and helium lines are broad and diffuse, and the two plates taken in 1901 with three prisms offered little hope of successful measurement. There is a considerable difference in the appearance of the same lines on the different plates of series IB, and it is quite likely that the lines are complex. This gives the effect of maxima of intensity within the broad lines, and in some cases the two observers have evidently not set upon the same point in a line, whence the resulting radial velocities for the two observers are quite widely discrepant. The combination of the results into a single mean would in such a case evidently be incorrect, as the lines dealt with are not the same for the two observers. Accordingly, where instances of this sort are encountered, as in IB 228 and 261 of the table above, we have left blank spaces in the mean velocity column. We consider, however, that the range shown

by the other plates of the star is sufficient to establish the variation, quite apart from the evidence in the same direction afforded by the complexity and changes in the lines themselves.

θ^1 Orionis ($\alpha = 5^h\ 30^m$; $\delta = -5°\ 27'$; Mag. = 4.8).

The measurement of the hydrogen lines in the spectrum of this star is complicated by the superposition of the bright nebular lines. A similar effect is apparent at the helium line λ 4472, where at least one bright line is present, and there is some evidence of further complexity, although in this case the bright line may belong to the star and not to the nebula. We shall discuss this matter, as well as other interesting features of the spectrum of this star and other stars in the trapezium, in a later paper.

The range in velocity which we have so far found for this star amounts to over 60 km.

θ^2 Orionis ($\alpha = 5^h\ 30^m$; $\delta = -5°\ 29'$; Mag. = 5.3).

This star is Bond 685, and follows the trapezium about 6^s, south 100″. The hydrogen and helium lines are broad and diffuse, and hard to set upon, though not complicated by nebular lines. A range of about 140 km in the radial velocity is indicated on the first four plates. The details of the measurements will be communicated later.

σ Orionis ($\alpha = 5^h\ 34^m$; $\delta = -2°\ 39'$; Mag. = 3.8).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 210	1903, Dec. 1	$20^h\ 55^m$	F. A.	+17	+20	3	4	+18
222	Dec. 25	20 28	A.	+31	+38	3	3	+35
250	1904, Jan. 2	18 14	A.	+16	+11	5	4	+14

Two plates of this star taken early in 1903 with a dispersion of three prisms led to a suspicion of variability in its velocity. The plates, however, were not well adapted to measurement, and no attempt was made to measure them in other than an approximate way. In the list given above all of the plates are noted as good. The spectrum is characterized mainly by the strength of

its helium lines, which are, in most cases, fairly well defined. There appear on one or two plates to be evidences of complexity in the spectrum, but these are scarcely sufficient to justify conclusions on the subject.

ξ Orionis ($\alpha = 6^h\ 6^m$; $\delta = +14^\circ\ 14'$; Mag. = 4.4).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
IB 184	1903, Nov. 7	$22^h\ 53^m$	F.	+13	− 8	3	4	....
264	1904, Jan. 23	17 47	F. A.	+46	+34	3	5	+40
275	Jan. 29	15 8	A.	+18	+18	4	4	+18

In the case of this star also the first evidences of variability were furnished by two plates taken early in 1893 with a dispersion of three prisms. Under high dispersion, however, the lines in the spectrum are so excessively diffuse and vague as to render measurement practically impossible. The plates taken with one prism which are entered in the list above show a very great improvement in this respect; yet, in spite of this, accurate measurement is extremely difficult, and the results given are subject to considerable uncertainty.

S Monocerotis ($\alpha = 6^h\ 36^m$; $\delta = +9^\circ\ 59'$; Mean Mag. 4.6).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
A 307	1902, Jan. 8	$20^h\ 15^m$	A.	+35	+32	3	3	+33
B 276	Jan. 16	15 41	A.	+25	+34	3	3	+28
A 437	1903, April 16	15 7	F. A.	+31	+41	2	4	+36
IB 189	Nov. 14	23 23	A.	+22	+17	3	3	+19
236	Dec. 27	15 34	A.	+ 8	+14	3	3	+11

The investigation of the spectrum of this well-known variable star was begun by us about two years ago, but the variation in its velocity was not established with certainty until quite recently. The spectrum is characterized by broad, strong helium lines, traces of a few oxygen and nitrogen lines, and by the prominence of the two lines of hydrogen at $\lambda 4542$ and $\lambda 4686$. The last two

lines have been measured upon all of the plates, and when we have more accurate values of their wave-lengths their use will assist materially in increasing the accuracy of the velocity determinations. The results given above may, accordingly, be modified sensibly when these lines come to be included. We are not as yet in possession of sufficient data to draw any conclusions as to the relation between the period of the light variation and that of the velocity variation.

η Hydrae ($\alpha = 8^h\ 38^m$; $\delta = +3°\ 46'$; Mag. = 4.3).

Plate	Date	G. M. T.	Taken by	Velocity		No. of Lines		Velocity Mean
				F.	A.	F.	A.	
				km	km			km
B 490	1903, Feb. 4	$16^h\ 56^m$	F.	+5	+2	3	3	+4
IB 214	Dec. 1	23 20	F. A.	+10	+1	5	5	+6
225	Dec. 25	23 22	A.	+26	+26	6	6	+26

We expressed, in March 1903, our suspicion of a variation in the velocity of this star. This has been confirmed by our recent plates. Among the early plates, three, which were obtained under very unfavorable conditions, were too weak for more than rough measurement, and are not included in the list above. The spectrum is difficult of measurement, and there appear to be evidences of the presence of maxima in some of the lines.

The plates measured by Frost in this paper were reduced by Miss Emily E. Dobbin.

YERKES OBSERVATORY,
February 8, 1904.

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